ONR Report ACR-108

Project Sealab Summary Report

An Experimental Eleven-Day Undersea Saturation Dive at 193 Feet

Sealab I Project Group

H. A. O'NEAL, *Office of Naval Research*
G. F. BOND, CAPT USN, *U.S. Naval Medical Research Laboratory*
R. E. LANPHEAR, LCDR USN, *Office of Naval Research*
T. ODUM, *Mine Defense Laboratory*

June 14, 1965

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
Washington, D.C.

PREFACE

Project Sealab I was the U.S. Navy's first step into "inner space." The actual operation, of course, represented many years of dedicated research and devotion to the cause of man's total conquest of the oceans.

No one discounts the strategic military importance to be derived from a more thorough understanding and complete utilization of the sea. However, the undersea research efforts of the Navy are helping to point out the vast resources within the sea which are available to the benefit of all mankind.

This detailed report of the conclusions drawn from Project Sealab I is published by the Navy so that all may share the information.

J. K. LEYDON
REAR ADMIRAL
UNITED STATES NAVY

CONTENTS

ABSTRACT

The Office of Naval Research, in conjunction with other U.S. Navy activities, has carried out an experiment in placing subjects in an underwater habitat for eleven days. An undersea, ambient-pressure, gas-filled, nine-foot-diameter by 40-ft-long laboratory was placed on the ocean floor off Argus Island near Bermuda. Four men occupied the laboratory. During this period of saturation "diving" on a He-O_2-N_2 gas mixture, the men performed work, ate, and slept within the dry laboratory and made working swims in the ocean spaces surrounding the laboratory. Physiological observations and measurements were made of the laboratory occupants. Logistic support was provided from the large covered lighter YFNB-12 and from Argus Island.

The aquanauts lived at ambient pressure equal to the depth of the habitat. The habitat, Sealab I, was designed and built at the U.S. Navy Mine Defense Laboratory, Panama City, Florida. It was utilized in an actual operation designed to examine, under open-ocean conditions, problems of men living and conducting work tasks under continuous high pressure in a set time frame, as compared with the time required for conventional divers to dress, descend, work, and ascend through decompression stops. During the period of Sealab I occupation, the aquanauts lived in the relative comfort of an underwater habitat, whereas with conventional systems the diver is exposed to the stress of being compelled to dangle on a stage in very cold and uncomfortable diving dress for several hours after accomplishing only a few minutes of useful work on the bottom.

The Sealab subjects reached a state of equilibrium (tissue saturation) with their breathing medium at depth during the first 24-hr period on the bottom. After this time, additional exposure did not increase the decompression schedule. Decompression time from a "saturation" dive to 200 ft may be as little as 30 hr, depending on conditions.

Sealab I project demonstrated:

1. That man can perform useful work at 200 ft and deeper with this technique of integrating the human more fully with his undersea environment, rather than having him make brief, expensive forays into it, always returning to surface pressure for his necessities of life.

2. No adverse physiological effects as a result of aquanaut exposure to the experimental conditions of the Sealab I project.

PROJECT SEALAB SUMMARY REPORT

AN EXPERIMENTAL ELEVEN-DAY UNDERSEA SATURATION DIVE AT 193 FEET

PROJECT OBJECTIVES

Project Sealab I is the first of a series of exploratory field trials of undersea habitats which will be used in a continuing sequence of deep-water studies. The purpose of these studies is (a) to confirm shore laboratory investigations of the physiology of saturation diving, (b) to determine the characteristics and suitability of undersea habitats for the support of swimmers performing various tasks in offshore waters, and (c) to determine man's efficiency in the performance of various classes or tasks while living under saturation conditions.

BACKGROUND

Man's exploration of the vast ocean depths represents one of the most demanding areas of present applied research. This research offers considerable promise of developing technology which will be directly applicable in strengthening the immediate operational capability of the Navy; it will also aid in defining additional research required to further future Navy capability.

One general area of research, which may be of extreme value for ultimate naval application, is the extent to which man himself can be integrated with the ocean environment. For example, what work functions can man perform without the need for complete environmental separation, as in "closed-hull" submarines?

Navy divers and underwater swimmers are able to perform specialized tasks which can be accomplished best, most economically, and most quickly by man himself. However, depth and duration limitations, manifested primarily by the requirement for extended periods of decompression after only brief working periods at depth, lead one to search for concepts radically different from the conventional diving approach. Extensive pressure-chamber studies by Dr. George Bond at the U.S. Naval Medical Research Laboratory, New London, Connecticut (Submarine Medical Center), and by Dr. Robert Workman of the Experimental Diving Unit, Washington, D.C., have demonstrated that man can live in an artificial helium-oxygen atmosphere at a simulated depth of 200 ft for prolonged periods and not realize any harmful effects.

During the latter half of 1963, the Office of Naval Research became interested in proposals by Dr. George Bond to apply in an ocean environment the results of several years of research on human abilities to live and work under the ambient pressures found at depth. It appeared that such a project would fill an acute Navy need for actual data on the "man-in-the-sea" concept also being investigated by CAPT Jacques Cousteau and Mr. Edwin A. Link. Although almost all of the basic physiological studies that made long-duration deep diving possible had been done under U.S. auspices, the U.S. Navy had not conducted tests in the open ocean. Indeed, the Navy seemed to be "left at the post"* by the well-publicized efforts of CAPT Cousteau and Mr. Link.

Dr. Bond had made several proposals for an ocean trial of the concept of saturation diving, ranging from utilization of a bottomed SSN as an ocean-floor habitat to conversion of a spherical "Texas Tower" escape capsule to support two or three divers for several days. The SSN

---

*It must be noted that while an air of "friendly competition" exists between the groups, there is much interchange of information; both CAPT Cousteau and Mr. Link had representatives at the Sealab I operation. The Navy has furnished considerable physiological data to enable these groups to successfully decompress their subjects, and to assure safety of the synthetic atmosphere required for the experiment.

proposal suffered from the difficulty of obtaining exclusive use of high-priority fleet units for significant times. The proposed Texas Tower escape capsule would, at best, be a cramped and marginal device. ONR's decision to initiate research in man living in the sea resulted in a plan to construct a habitat which would be specifically designed to investigate the specific problems of man's ability to work in high-pressure environment.

Experience in the design of deep underwater swimmer housing did not exist, nor was there sufficient information from which extrapolations could be made to determine the optimum, or even acceptable, design criteria for such a structure. Consequently, a philosophy was required which accepted engineering judgment, backed by competent counsel in good seamanship and conventional diving techniques and supplemented by a willingness to experiment and learn from trials the techniques required to prevent critical situations from occurring which would impose overriding hazards to human life.

DEVELOPMENT OF A PLAN OF ACTION

The Bureau of Ships has a long history in extending the Navy diving capability. Consequently, a conference with BuShips was held in December, 1963, during which Bureau support was obtained. It was also tentatively decided that the U.S. Navy Mine Defense Laboratory, Panama City, Florida, would provide design and shop services for construction of the habitat to be used in the project, now titled Sealab I. Of utmost value to the design engineers would be the Mine Defense Laboratory's swimmer R&D group, which could provide competent advice.

It was felt that the primary considerations affecting the location to be selected for Sealab I should be (not necessarily in this order):

1. Prospect of good weather
2. Good underwater visibility
3. Level bottom
4. Moderate water temperature at depth
5. General features of oceanologic and marine biological interest.

The site adjacent to Argus Island (Fig. 1) seemed to be ideal with regard to the above criteria; thus, it was felt that whatever disadvantages would accrue from selection of this site (such as remote location, lack of swell protection, and absence of extensive support facilities) would be outweighed by the above advantages.

Based on these plans, approval was requested and received from the Assistant Secretary of the Navy (R&D) to embark on this project; early in February a formal request was made for fleet assistance in carrying out the operation. In March, the Chief of Naval Operations assigned the Commander Operational Test and Evaluation Force (COMOPTEVFOR) to coordinate fleet support as provided by CINCLANTFLT. The large covered lighter, YFNB-12, was made available for the duration of the project to serve as the principal support vessel for Sealab.

Plans were formulated to complete the underwater structure and to organize the operation to be conducted during the summer of 1964.

SEALAB I DESIGN, FABRICATION, AND PRELIMINARY INSTALLATION TRIALS

In discussions with MDL, it was decided that a suitable shell for the main body of Sealab was already in existence in the form of some old experimental minesweeping floats and that work should start as soon as possible to fit one out as a laboratory. (See Appendix A for detailed Sealab I description.) Figure 2 shows the internal arrangement of the float as modified for Sealab. Design and shop work commenced concurrently in late March. The ONR project officer and the MDL engineering and shop force readied the hardware for this project

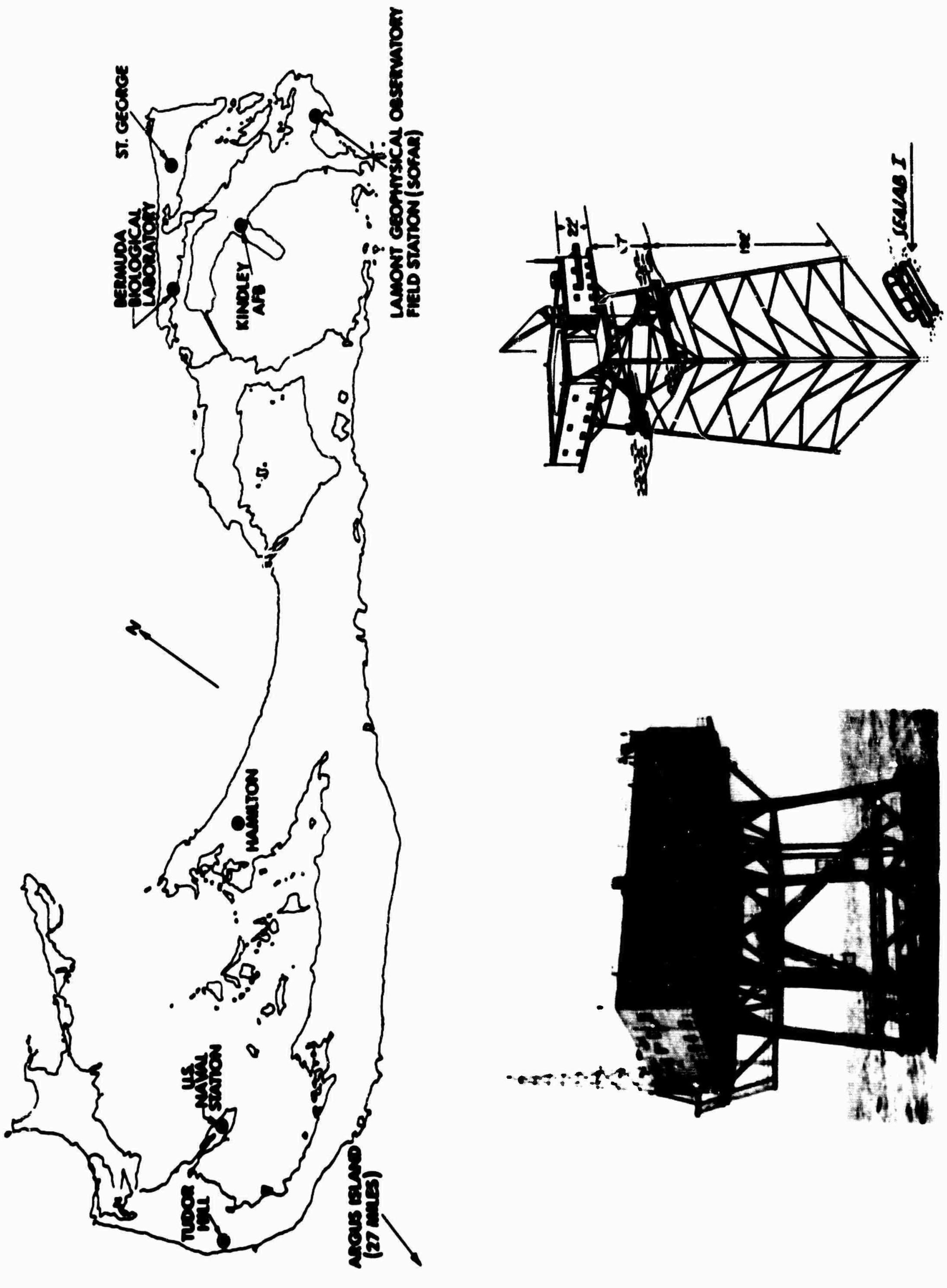
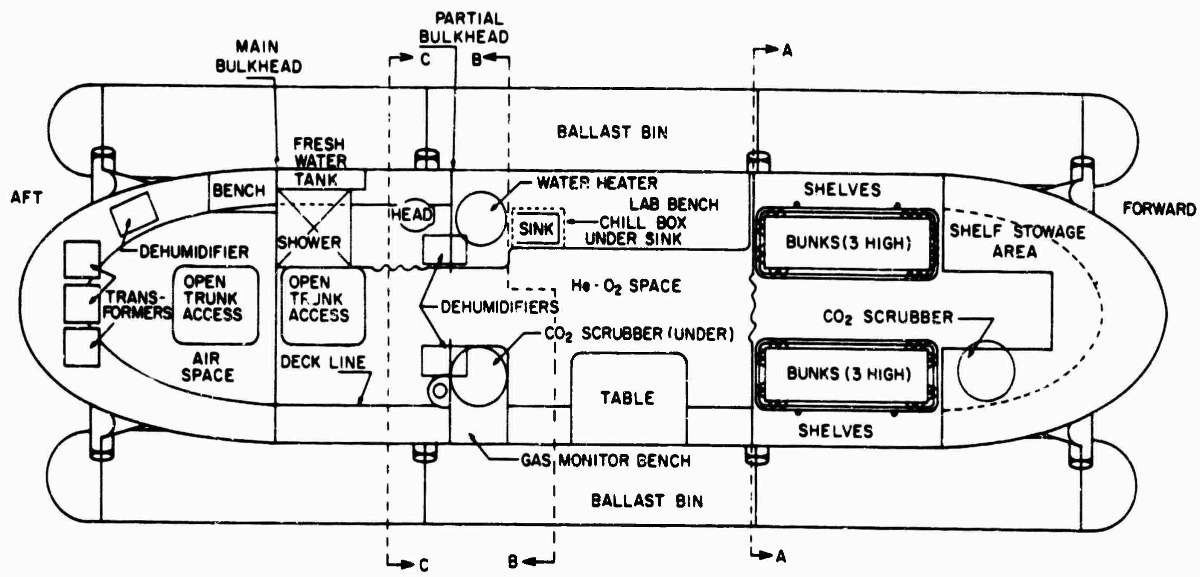
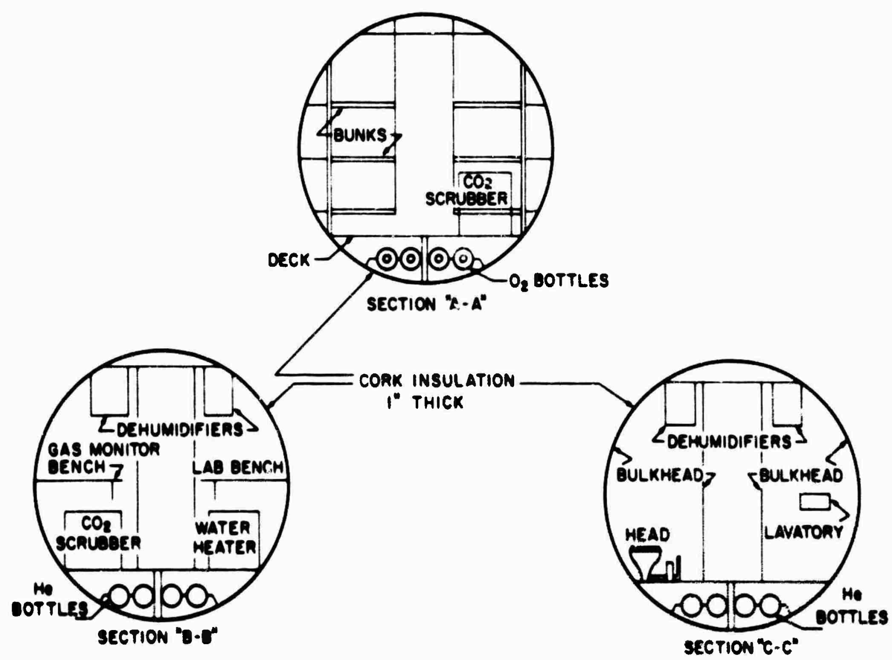


Fig. 1 - Sealab I site, 27 mi southwest of Bermuda



(a) Plan view



(b) Cross-section views of Sealab, at intervals shown on Fig. 2a

Fig. 2 - Internal arrangement of minesweeping float as modified for use as Sealab I

in the short space of three months.* (Figs. 3, 4, 5, and 6 show Sealab I during construction and after its completion.)

On May 20, 1964, Sealab I was ready for sea trials and was waterborne. On May 22 the YFNB-12 and Sealab I were towed to sea near Stage II (an offshore tower in 60 ft of water) off Panama City, Florida, and the Sealab was made ready for a test lowering. Final ballasting was done the morning of May 23, and slight negative buoyancy was attained. Due to a misunderstanding in linehandling orders, Sealab sank about 10 ft below the surface. Since the bottom hatches were open, and since there was not sufficient air blowing into the Sealab to keep water out, it picked up tons of extra ballast and sank out of control to the bottom in 60 ft of water. While several nylon lines tending Sealab were burned during the uncontrolled descent, none parted and no one was injured.

Sealab I was found to be flooded over half full of sea water. The Sealab was blown dry, and preparations were made to lift it from the bottom. Since Sealab was ballasted only about 1,000 lb negative, as soon as it was lifted from the bottom, the expanding air began to bubble from the bottom hatches. Sealab thus created its own buoyancy and came riding to the surface. Quick action on the part of the linehandlers and winch operators prevented it from sinking a second time. Sealab was towed back into port, and MDL worked around the clock to get it ready for additional sea trials.

By noon on Tuesday May 26, Sealab I was waterborne and underway on additional installation trials. On Wednesday, May 27, Sealab I was successfully lowered to the ocean floor in 60 ft of water and left for a period of 30 hours to test all systems. It was not manned during this period. With the test completed, the Sealab was recovered, and it and the YFNB-12 were towed to port. Preparations were then made to get underway for Bermuda, with a sailing date of June 6. Arrival at Argus Island was June 12.

ARGUS ISLAND INSTALLATION

After a month of checkouts (Fig. 7), loading, transiting to Bermuda, ballasting (Fig. 8), and delays caused by weather and search support required for one nonassociated aircraft accident, the YFNB-12 on July 14, was centered in a four-point moor off Argus Island. Sealab I was astern and ready for lowering to the ocean floor. Seas were from the south (3 to 5 ft swells), and all systems were in order. Sealab was ballasted to 3,000 lb negative buoyancy and slowly lowered beneath the surface.† The large effective mass plus hydrodynamic drag limited the vertical motions of the sealab in the water; the YFNB-12, however, followed the prevailing swells. The resulting loads on the supporting nine-inch nylon were in excess of 140,000 lb. The stretch of the nylon allowed Sealab to sink to 40 ft before it could be stopped. Some water was taken in through a drain valve that had inadvertently been left open. The resulting flooding was not disastrous, but it was sufficient to ground out some of the electric circuits and equipment that were on the Sealab deck. The operation was aborted, and all ships returned to port. At this time, it was decided that Sealab I could not be satisfactorily lowered by the YFNB-12 with the equipment then available.

In order to proceed with Sealab I, a method of handling the Sealab from the crane on Argus Island was adopted, and on Saturday, July 18, Sealab was again at Argus Island. Sealab was ballasted (by the YFNB-12) to 3,000 lb negative while suspended from four 60-in. spherical buoys, and then was towed under the Argus Island crane. Air supply was connected for pressurizing, the Argus crane took the weight of Sealab, and the flotation buoys were tripped clear. As soon as Sealab was on the Argus crane, the third encounter with underestimated forces was met – the surge action of the waves. High surge loading of the crane was encountered, and Sealab was rapidly concurrently pressurized and lowered to the ocean floor (Figs. 9, 10).

*Close laboratory-ONR cooperation was developed, resulting in a high esprit de corps, which helped shorten the design time. Most observers felt that it would be surprising if the project were completed in a year.

†The Sealab trunk entrance was sealed off for this and the second preliminary trial installation. Gas venting was obtained through a cable access pipe.

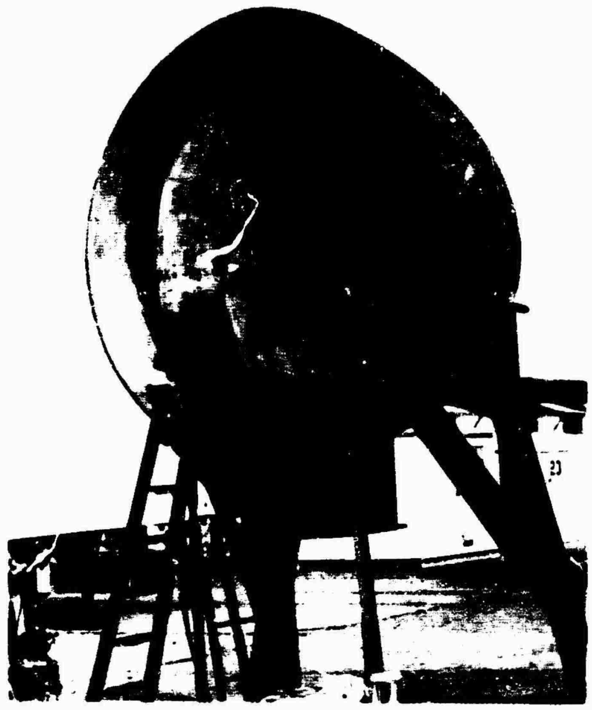


Fig. 3 - Transformer room of Sealab during construction. Note the layer of cork insulation being applied to the inside surface.

Fig. 4 - Internal view of main section of minesweeping float after start of modification for use as Sealab

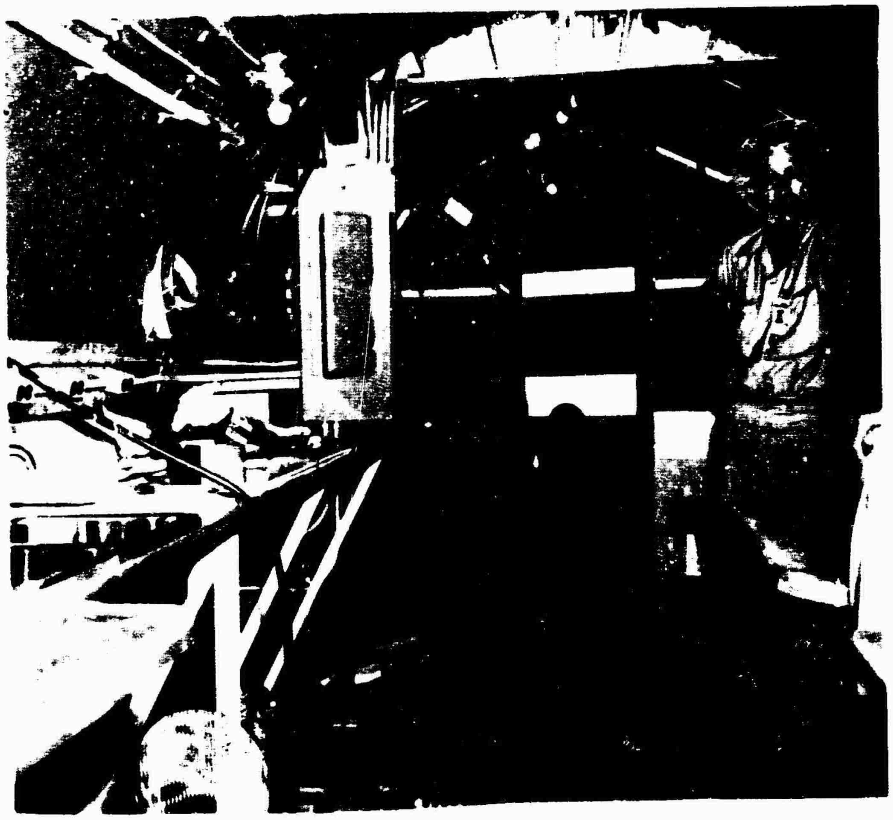


Fig. 5 - Fitting-out fabrication in main compartment of Sealab. The cage shown at one end of the laboratory will house the sleeping and storage areas.

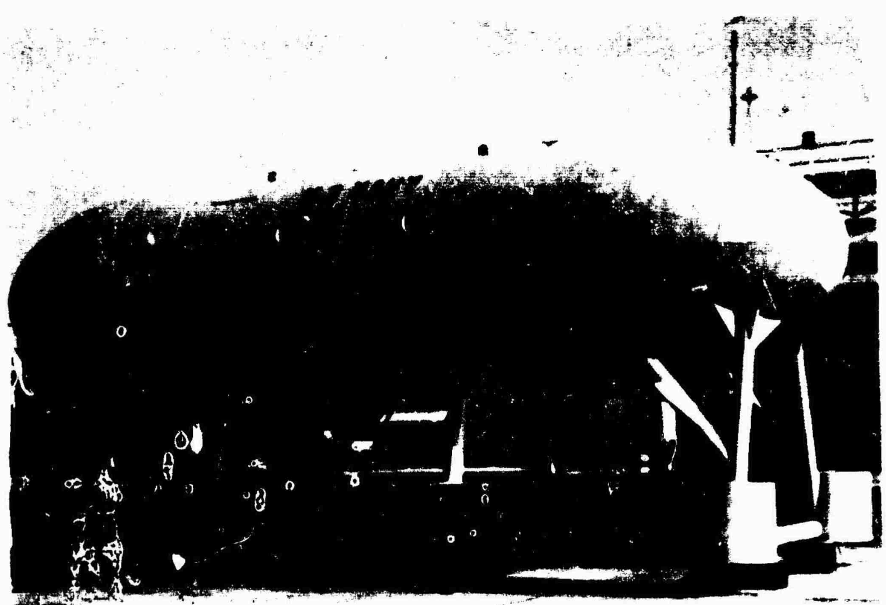


Fig. 6 - Sealab after completion at the Mine Defense Laboratory

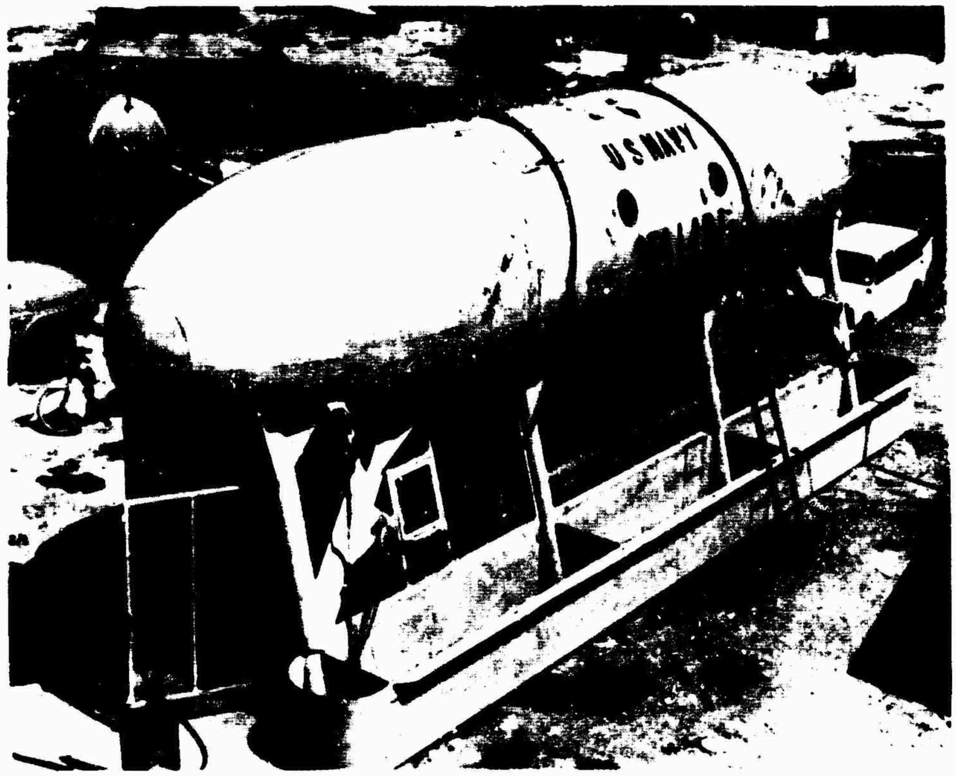


Fig. 7 - Sealab receiving final checkout at Bermuda prior to start of operations. The opened wire mesh door to the left leads to a screened-in room beneath the labcratory, referred to as the "back porch," or shark cage. Undersea life can be observed from here in safety. This room leads into the dry portions of the laboratory through the open trunk access shown in Fig. 2a.

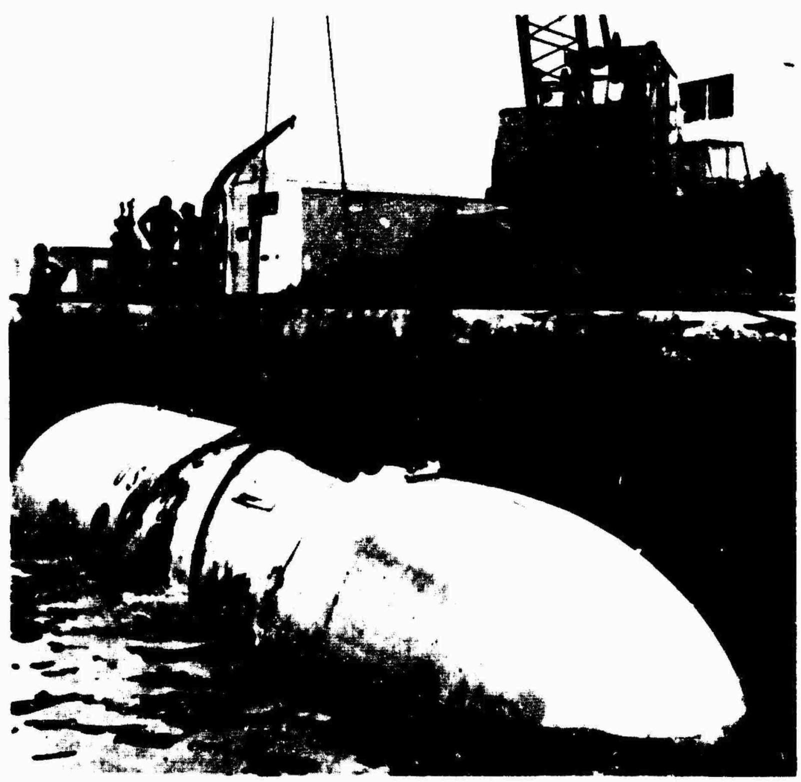


Fig. 8 - Sealab being ballasted with railroad car axles at Bermuda

Fig. 9 - Sealab being lowered into sea

The main hatch cover of the Sealab was removed (Fig. 11). The umbilical cord was then lowered to the Sealab, inserted into the umbilical-cord entrance pipe, and the umbilical cables connected into the internal junction boxes (Figs. 12, 13, 14). The umbilical cord contained supply lines for the Sealab for power, water, communications, breathing gases, and Sealab atmosphere sampling. (See Appendix B for detailed discussion of the cord.)

OCCUPATION OF SEALAB I

On Monday, July 20, 1964, at 1735, Sealab I was manned after a 24-hour checkout while on the bottom (Appendixes C, D, E). The swimmers used the submersible decompression chamber to descend to 165 ft and then swam to the Sealab (see Figs. 15, 16, 17).

The Sealab was found in the following condition:

Sealab proper:	Dry and habitable
Atmosphere:	Satisfactory, temperature 78°F, chilly
Water supply:	Water not available
Heaters:	Operable
TV monitor:	Not hooked up properly
Hot water heater:	Not operating

Fig. 10 - Sealab on ocean floor. Note the structure of Argus Island in the background.

Fig. 11 - Aquanaut working on hatch cover of Sealab living quarters

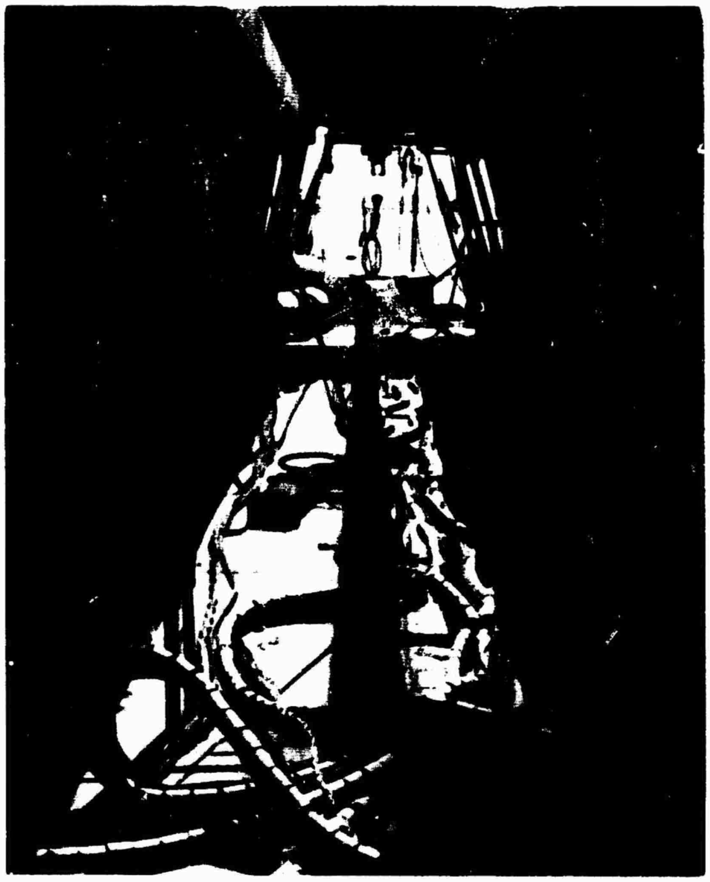


Fig. 12 - Umbilical supply line which will link Sealab to her support vessel YFNB-12 during the submergence period. The umbilical is a package containing a fresh-water line, electrical power cables, communications lines, TV, telephone, electrowriter, telegraph, hoses for compressed air and helium, and an atmosphere-analysis sampling line.

Refrigerator:	Not operating
CO_2 scrubber:	Satisfactory
Electrowriter:	Satisfactory
Calibrated microphones:	Not functioning
Krasberg O_2 meters:	Satisfactory
Lights:	Satisfactory

The faulty equipments were corrected, except for the calibrated microphone and the thermoelectric refrigerator.

The subjects slowed their pace of activity upon reaching the Sealab. Fatigue was noted, coupled with shoulder joint discomfort. Appetites remained good, and digestion and elimination were normal. Sensory perception appeared to be unchanged. Joint discomfort eased during the occupation. See Figs. 18 through 24 for aquanauts in and around Sealab during occupation.

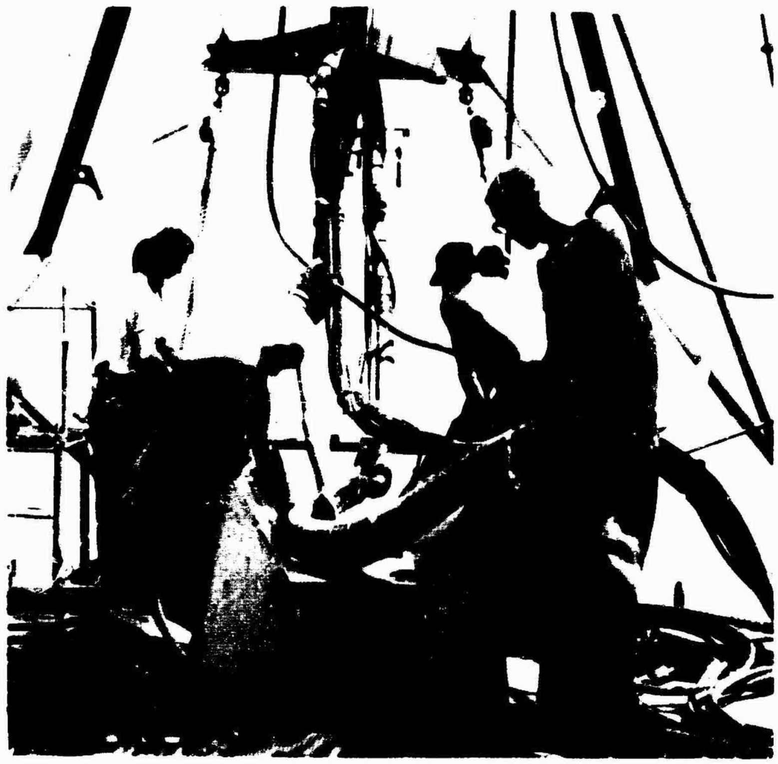


Fig. 13 - Umbilical cord being lowered to Sealab

Fig. 14 - Umbilical cord being inserted into entrance pipe to Sealab

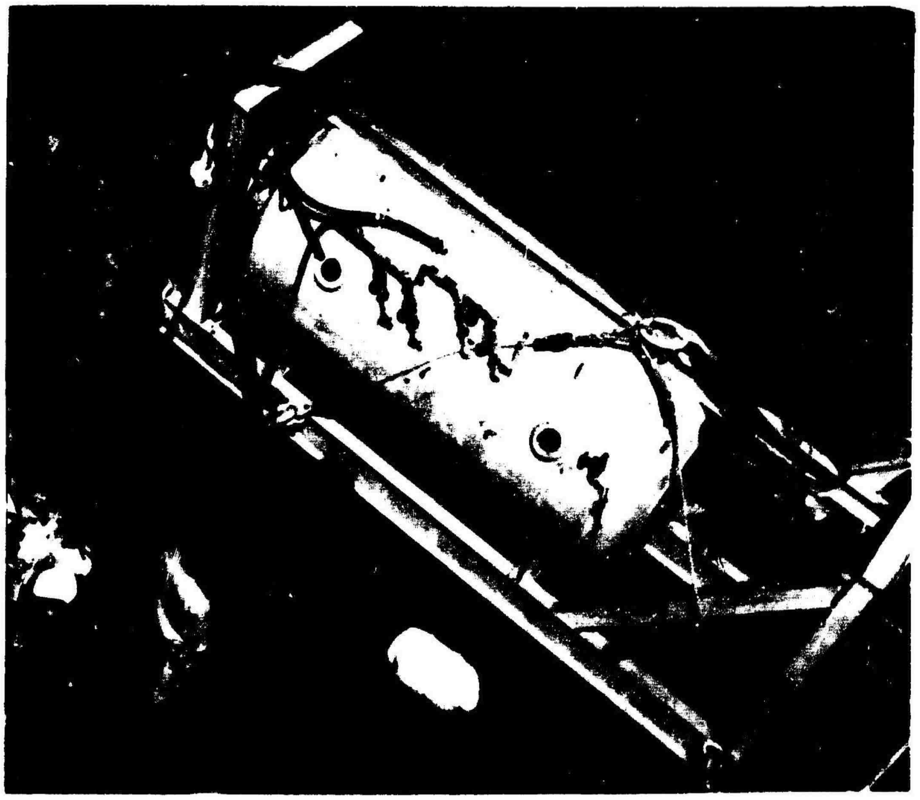


Fig. 15 - Submersible decompression chamber on deck

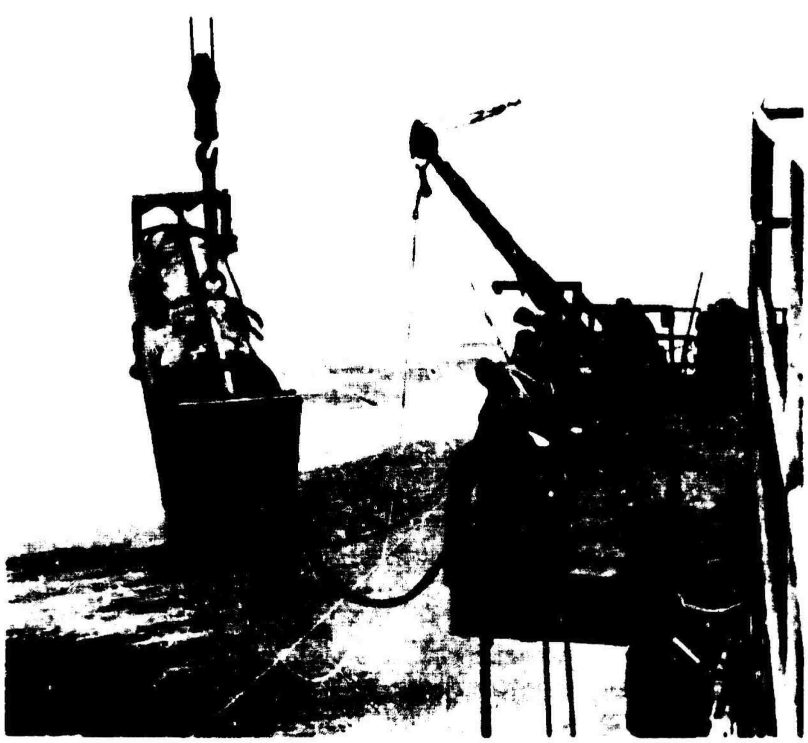


Fig. 16 - Submersible decompression chamber
being handled by Argus crane

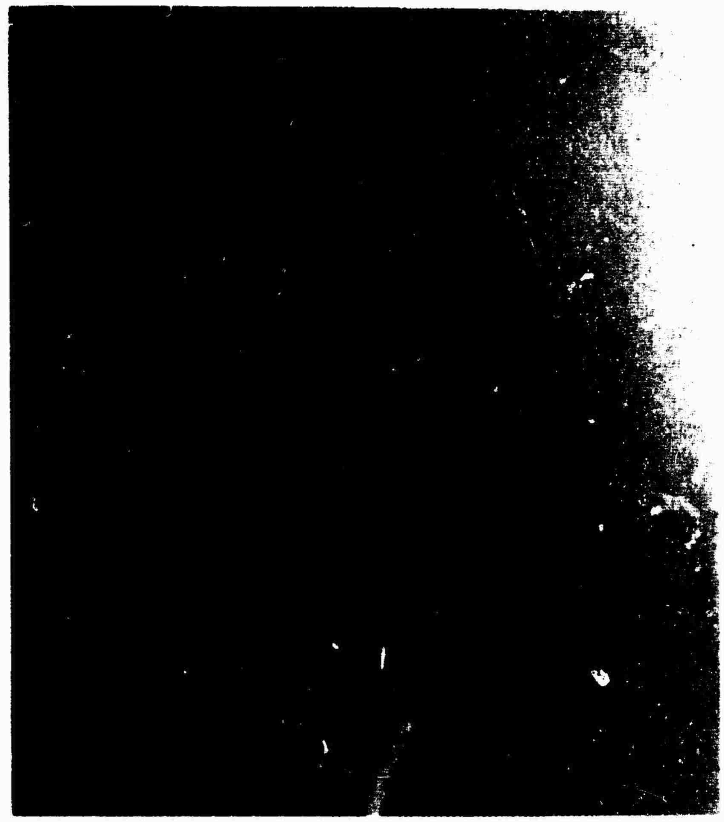


Fig. 17 - Submersible decompression chamber lowered near Sealab

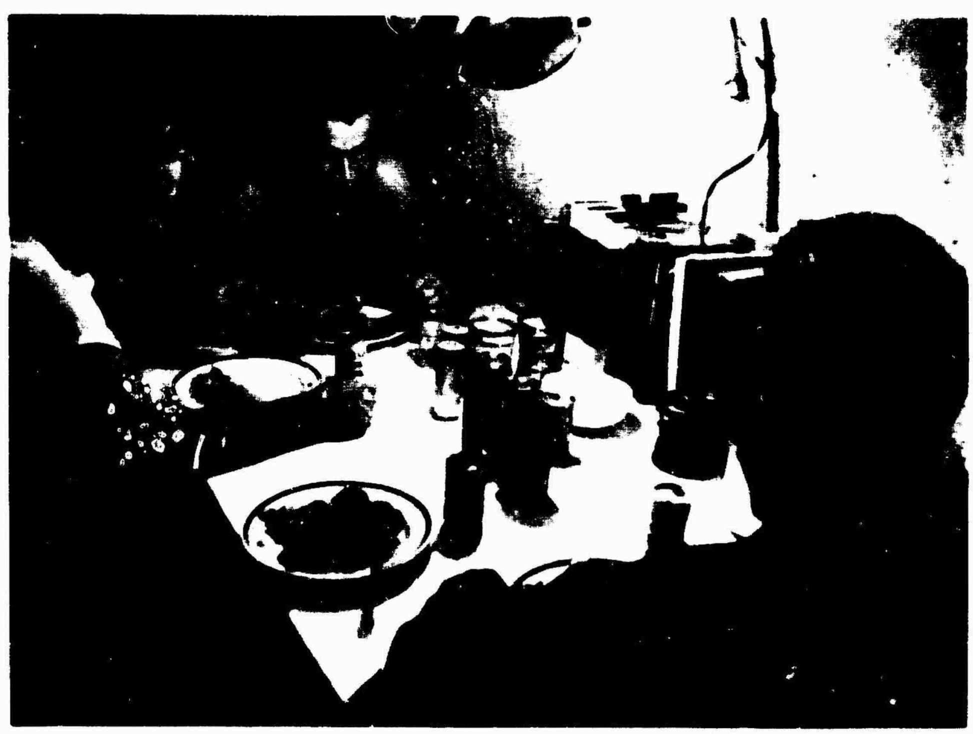


Fig. 18 - Subjects eating in Sealab during occupation

Fig. 19 - Subjects discussing physiological measurements taken during occupation of Sealab

Fig. 20 - Fish-watching from Sealab at night

Fig. 21 - Swimmer with underwater camera

Fig. 22 - Aquanaut Thompson and a surface-support diver engaged in gathering marine biological samples. Note that Thompson is breathing from the "hookah" hose, which allows him to travel in a limited radius from the Sealab without scuba gear. The hookah apparatus supplies Thompson with the same helium-oxygen mixture as that inside the Sealab.

Fig. 23 - Aquanaut entering shark cage

Fig. 24 - Aquanaut entering submersible decompression chamber

Fig. 25 - Mk 6 He-O_2 mixed-gas scuba gear used by Sealab occupants. The fat-bottle design on the right was found to be unacceptable because of center-of-gravity shift, and the standard tanks on the left had to be used.

The subjects performed work tasks outside of the Sealab, investigating the marine life and the tower legs, cleaning up the debris on the ocean floor surrounding Sealab, taking photographs of the Sealab operation and that of a small one-man submersible (STAR I) which was sent into the area for evaluation purposes.

Two incidents of significance occurred during the occupation. A swimming accident of a serious nature occurred on the eighth day, and two swimmers suffered from nitrogen narcosis on the fourth day.

The swimming accident (Appendix E) occurred to subject Manning. Manning apparently struck his gas-control yoke against the Sealab structure and accidentally closed the valve. After depleting his oxygen while swimming. Manning noted that he was in trouble and dashed for return to Sealab. He lost consciousness in the shark cage. Subject Anderson heard Manning's bottles hit the Sealab hull and went to the hatch to give Manning additional film. Instead, Anderson sighted Manning drifting in the shark cage. Fast response by Anderson in recovery of Manning's body. bringing his head above the water, and applying resuscitation, and additional aid by Dr. Thompson and Chief Barth resulted in the successful rescue of Manning. Except for a severe hemorrhage in the conjunctivae (whites) of the eyeballs, no other evidence of damage to Manning was noted, and he remained active with the Sealab crew throughout the rest of the Sealab occupation.

The nitrogen-narcosis incident was the result of two of the subjects entering the air space of the transformer room of the Sealab without Mk VI gear (Fig. 25). Immediate narcosis resulted, and they had to leave the space. Helium was thereafter bled into the transformer space to prevent further occurrences of this nature.

The men, during the occupancy of Sealab, accentuated their personal idiosyncrasies. During one period, excessive use of foul language developed, as well as an independent attitude with respect to the surface support. This attitude subsided, however. They showed little or no apparent tension with regard to the safe control of the environmental situation.

Blood samples, urine samples, electrocardiograms, and other physiological measurements were taken on a routine basis of the subjects during the occupation (see Appendix D for details). In general, it may be said that insofar as preliminary examination of the data is concerned, no adverse physiological effects were noted as a result of the aquanaut exposure to the experimental conditions of Sealab occupation.

During the occupation of the Sealab, the temperature was kept near 84° F and was comfortable with a relative humidity of, approximately 72 percent. It was found experimentally that air was quite adequate for atmosphere make-up during the occupation. From measurements of CO_2 and N_2 made during the occupation, it appeared that the sea-water interface in the entrance trunk served as a good absorber of both, thus making air make-up possible.

It is to be noted that during the occupation the helium speech unscrambler aided significantly in communication between the Sealab and the control station at the surface.

A dumbwaiter was installed to ease the problem of delivery of material to the Sealab from the surface. The general problem of supply and housekeeping during the eleven-day occupation consumed excessive time on the part of the subjects (as well as surface personnel).

A new concept of supplying breathing gas to swimmers operating out of the Sealab was attempted during the occupation. The system, dubbed both as a hookah and Arawac gear, consisted of a delivery and return hose leading to the swimmer from the Sealab. However, the experimental system used was found to be inadequate and needing further development. The basic concept, however, was felt to be of value in future Sealab-type operations.

RECOVERY OPERATIONS

On Wednesday, July 29, unfavorable weather predictions prompted termination of the experiment, and at 2356 Sealab was lifted off the bottom. The ascent, one foot every 20 min, was uneventful until Sealab was at about 110 ft, when wave forces began to make themselves felt again. The ascent was stopped at 100 ft for several hours, hoping for abatement of the seas, and finally started again. Sealab was brought to 81 ft, at which point shock loads in excess of 20 tons were being put on the crane. Further ascent was not considered safe.

The subjects were transferred to the submersible decompression chamber (SDC) (Fig. 26) and brought up on Argus Island. Sealab was floated off on the same four buoys that were used to transfer it to Argus and brought astern of the YFNB-12. Ballast weights were jettisoned until positive buoyancy was attained and Sealab floated. Once on the surface, it was secured for sea and towed back to port with the YFNB-12.

Sealab subjects were taken out of the decompression chamber at 0830, Aug. 1, and were flown by helicopter to Kindley Air Force Base Hospital for examination. All Sealab equipment was packed and stowed for shipment, and with a press conference and congratulations by RADM J.K. Leydon, Chief of Naval Research, at 1130 on Aug. 4, 1964, Sealab I was terminated.

Fig. 26 - Observer checking subjects after recovery of submersible decompression chamber and completion of decompression, before hatch opening

MAJOR FINDINGS

Systems

Handling System - It proved to be even more difficult than anticipated to handle the large high-drag mass of Sealab from a heaving platform, in attempting to place it on the bottom. The heaving of the barge in a fairly long-period sea (10 to 12 sec) placed severe strains on the handling lines and made a controlled descent from the barge unfeasible. While lowering Sealab from a fixed platform (Argus Island), dynamometer readings on the wire used to lower it indicated that, for this hull configuration and mass, wave action could be felt clearly at 120 ft (4 to 5 ft seas, 10 to 12-sec period) and became of real concern by the time the hull was at 80 ft. It was further demonstrated that unless a definite overpressure is maintained in the hull prior to lowering, some hull fitting, invariably left open, will cause flooding.

Initial Gas Filling of Sealab - The gas filling of Sealab I was accomplished as the Lab was being lowered. In fact, the lowering rate was limited by the rate at which gas could be bled into the Sealab to prevent water entry as the lab was lowered. This problem could be circumvented by pressurizing the Sealab prior to lowering. The habitat in this case, however, would have to be designed as a pressure vessel.

Gas Supply - Monitoring of the gas composition revealed that the nitrogen percentage steadily decreased, probably due to solution in the sea water. It was found possible to use compressed air for makup of oxygen, since the nitrogen seemed to disappear about four times as fast as oxygen. No appreciable loss of helium was noted during the course of the operation.

Dehumidification - The installed dehumidifiers worked at near rated capacity, removing about 6 gal/day of water from the He-O_2 space. The humidity was maintained at levels varying from 68 to 74 percent. Contributory factors in these variations were open water surface in the entrance trunk, hot showers on completion of excursions, wet suits hung up, and moisture in exhaled breath.

Thermal Control - Much less heat was required to maintain comfort than had been predicted. The cork insulation in the He-O_2 space re-expanded to its initial 1-in. thickness within a few hours on the bottom, while that in the air space became compressed on the way down and never did expand. This difference is probably due to the increased diffusion rate of helium over that of nitrogen.

Swimmer Support - The wet suits which went down "dry" in Sealab quickly re-expanded to their original thickness. Those worn down by the subjects never did expand. The reason for this difference is unknown. Protection provided by even the re-expanded suits was inadequate to take full advantage of the time available for working excursions.

The hookah equipment, used to pump the Sealab atmosphere to and from a swimmer, failed to perform satisfactorily. The gas pumps were noisy, overloaded, and had to be placed in series to provide enough gas to support one swimmer. This concept is very attractive, but the present equipment is inadequate.

Subjects

The subjects (Appendix F) acclimatized to a chamber temperature of 84°F, somewhat lower than expected in this atmosphere, which enhances body heat removal. The exact effects of the presence of the small amount of nitrogen on this heating problem are still unknown.

The gas mixture was held close to 4 percent O_2 (200 mm), 17 percent N_2 (850 mm), and 79 percent He (3950 mm). The subjects expressed the general conclusion that this somewhat higher partial pressure of oxygen was desirable, although no specific performance measurements were made. The subjects' conclusion was based on a reported "increased sense of well being" immediately after oxygen additions, when the oxygen partial pressure was in fact somewhat higher.

During the first four days the subjects were somewhat uncomfortable, noting joint aches, etc. These were not serious, and did not debilitate the subjects, although a general slowdown of movement during this period was noted by the topside monitoring personnel.

There appears to be a significant increase in individual susceptibility to nitrogen narcosis after helium-oxygen saturation. This was noted when saturated subjects entered the air space in Sealab. LCDR Thompson noted that this narcosis was of a very uncomfortable variety which caused headaches and nausea.

Basic physiological parameters, i.e., blood chemistry, etc., did not deviate significantly from well-established baseline values. In previous chamber runs, deviations from baselines were noted, and baseline values were reapproached about the ninth day. This deviation did not appear to be the case in Sealab.

The personnel selection for Sealab is an open question. A comment has been made by attending psychologists that there were too many potential leaders and that this led to an unwarranted degree of independence below. Dr. Bond recognized this independence and noted that it probably was the cause of some neglect of the "buddy system" and what he considered undue use of breath holding during excursions from the lab. The subjects also commented on the feeling that the topside situation was somewhat confused and that this led to confusion in the relationship between the subjects and topside. This comment deserves careful consideration.

CONCLUSIONS

1. It is concluded that human subjects can live and work under pressure at 193 ft in the open ocean without significant physiological or psychological problems.

2. All major systems used in Sealab I worked in a fashion adequate for life support. Many of the systems were primitive, especially the habitat installation and retrieval systems.

3. The major mechanical problems, encountered in raising and lowering the habitat, were caused by surge of the habitat and surface ship. These problems were most serious from the surface to 100-ft depth. A major engineering effort is required for solution of this problem.

4. This concept offers a step toward increased efficiency in the utilization of human diver's time over existing techniques. Although, in this experiment, a maximum of four to five hours outside working time was maximum experienced, it appears that six hours outside work per man in each 24-hour period is practicable. The major losses of working time in this experiment were caused by inadequate preparation for housekeeping functions, and lack of adequate work schedules. Some working time was lost during the subjects' acclimatization period.

5. Techniques for largely overcoming the helium speech problem were demonstrated. However, fully satisfactory equipment is not yet in hand.

6. Provision for adequate body heating while swimming remains a major problem. Although this experiment was conducted in 69°F water, to which the subjects acclimatized to a significant degree, lack of heating for swimming imposed restraints on the subjects during excursions.

7. The submersible decompression chamber performed adequately for the purposes of this operation, but difficulty of handling it points up the desirability of a more compact unit which can be married to a larger surface chamber.

RECOMMENDATIONS

1. Major changes in habitat design and/or handling procedure must be initiated for future Sealab work.

2. A higher degree of independence from surface support must be achieved. A smaller, permanently attached umbilical cord must be provided. Specific items which must be improved are:

Gas supply

Gas control and monitoring

Power (at least for emergencies)

Communications.

3. As Sealab crews enlarge, at least one man must be assigned full time to housekeeping and equipment maintenance.

4. For further experiments, a major effort must be made in improvement of housekeeping (material and organization), and in time-and-motion studies and layout of work schedules.

5. Vehicles for swimmer transport must be provided. A usable one-man wet vehicle is now available; a two-man wet vehicle is anticipated. Consideration must be given to a dry vehicle with lock-in, lock-out capability to permit greater excursions in depth.

6. Physiological studies must be performed to determine the permissible time of depth excursions from saturation level under no decompression and under programmed decompression limits.

7. R&D must be performed to improve:

a. Gas sensors – desirable limits are: O_2 100 to 600 mm partial pressure, accuracy 10 mm

CO_2 5 to 50 mm partial pressure, accuracy 2 mm

b. Communication equipment – habitat to diver, diver to diver, diver to habitat, habitat to surface

c. Swimmer heating apparatus

d. Helium pumps – for gas mixing and helium recovery

e. Navigation equipment and techniques

f. Hookah pumps.

8. A submersible decompression chamber capable of being coupled with a surface decompression chamber must be provided.

9. It is recommended that a Sealab task group be established composed of 25 to 35 personnel, which will be the central group involved in future R&D work in the man-in-the-sea program, and that this group be established at some existing naval shore activity.

APPENDIX A

HABITAT DESCRIPTION

HULL

The Sealab hull was fabricated from two existing minesweeping floats. These floats were 57 ft long and 8 ft 11 in. in diameter, with an ellipsoidal nose, a cylindrical body, and a conical tail. Hull thickness varied from 3/8 in. at the top half of the nose section to 3/4 in. in the bottom 120 degrees of the cylindrical body section. For the sake of symmetry, reduced volume and trim problems, and ease of fabrication, the nose section of one float and the nose section and part of the body section of another float were utilized. The overall length of the hull is 40 ft, as required. Since the hull was not required to withstand the full pressure at operating depths, the hull thickness was not critical, other than for the required structural integrity for handling at sea. A maximum pressure differential of 15 psi was selected as a safe design requirement for all hull penetrations. The hull was divided into two compartments, with a gas-tight bulkhead, at a point 31 ft from the bow. The 31-ft forward compartment was utilized as the living or helium-oxygen space, and the after 9 ft compartment served as the utility or air space (Figs. 2a, 2b).

One vertical entrance trunk, 30 × 36 in. in cross section, was provided in each compartment, with the exterior opening below the hull. This arrangement provided for the desired free entry and exit of subjects without the necessity of locks. The trunk into the He-O_2 space extends 3 ft below the hull and 4 ft into the hull, for an overall length of 7 ft. This length was provided to contain the sea-water level over expected variations inside the hull. The trunk into the air space extends 1-1/2 ft below the hull and 1-1/2 ft into the hull. The shorter-length trunk was considered satisfactory here, since it was planned to have the air space continuously supplied with air, maintaining a slight internal overpressure. Both trunks were provided with watertight covers to prevent water entry during towing and lowering operations. Two inlets were provided in each trunk to facilitate pressurizing and pressure monitoring simultaneously.

Due to anticipated difficulties in obtaining and adapting watertight through-hull connectors for the power cables, signal leads, and miscellaneous gas, air, and water hoses, an umbilical entrance tube very similar to the entrance trunks was provided into the air space near the after end. This tube extends below the hull to just below the level of the air-space entrance trunk and up to approximately the horizontal center line of the hull. A watertight cover was installed at the top of the umbilical tube.

Two 12-in.-diameter deadlights were installed in each side of the hull in the He-O_2 space, and one was installed in the bulkhead between the He-O_2 space and air space. Internal watertight covers were provided, to be used in case of damage to the plastic lens of the deadlights. These covers were in turn penetrated with small petcocks to allow for pressure equalization during lowering and raising operations.

AIR SPACE

The air space was provided primarily to facilitate speech communications with the surface-support personnel and also to serve as a utility and storage area. It was also to serve as an emergency area in case of possible contamination of the He-O_2 atmosphere. The air space was also used as a staging area for the swimmers when leaving or returning to the Sealab when using Mk VI scuba gear. A padeye and block and tackle arrangement was rigged to facilitate handling the scuba gear in and out of the air space.

SUPPORTING STRUCTURE

The hull was fitted with 2 × 2 ft double plates at 12 points for attachment of the support legs and braces. All supporting structures were fabricated of 8-in. schedule 80 steel pipe. The height of the hull bottom was selected as 6 ft, which allows 3-ft clearance under the lower end of the $He-O_2$ entrance trunk. The overall height was kept as low as possible to reduce current drag and the resulting tilting moment. The overall base width, including ballast bins, was restricted to 14 ft because of space limitations aboard the YFNB-12. The supporting structure was purposely overdesigned to allow for corrosion damage.

BALLAST BINS

The ballast bins were fabricated of 1/2-in. steel plate and were designed as deep box beams in order to support the ballast load. They were placed outboard of the hull to allow for underwater ballasting and to provide maximum stability on the sea bottom within the width limitations imposed. The large bottom area of the bins served to reduce the unit bearing stress of the structure and in turn to reduce sinking into the soft bottoms. The ends of the bins were fitted with semicircular sections to reduce towing drag.

HULL INSULATION

Submarine cork insulation, one inch thick, was glued to the interior surface of the hull throughout with the exception of a two-foot-wide strip in the center of the bilge. This area was left uncovered to prevent odors and dampness which might be caused by cork in this area absorbing bilge water. In the air space the insulation was installed above the deck line only, for the same reason.

HEAT REQUIREMENTS

The heating and insulation system was designed to maintain a maximum temperature of 93°F within the Sealab while immersed in water at a temperature of 65°F. Heat-loss calculations with a one-inch thickness of cork insulation, using a thermal conductivity coefficient of 0.28 $BTU/hr/ft^2/in./°F$ for atmospheric conditions, indicated a heat loss of 5,964 BTU/hr, or 1754 watts. Since helium has a conductivity approximately six times that of air, and since the pressure in Sealab would be approximately seven atmospheres, it was anticipated that the actual heat loss under operating conditions would be somewhat greater than calculated. Pressure tests of the cork insulation material in a helium atmosphere proved that the helium would permeate the cork such that the cork itself would experience little if any increase in density. Therefore, it was assumed that the insulation efficiency of the cork would be decreased only by the presence of helium within the insulation and the increased density of the gases (helium and air mixture). Since time was not available for determining the thermal conductivity under operating conditions, and since electrical power for heat was readily available, an installed heat capacity of approximately 7000 watts was provided. Additional heat, approximately 4000 watts, would also be provided by other electrical equipment, including transformers, dehumidifiers, water heater, lights, etc. During operation it was reported that only one heater was required intermittently to maintain a comfortable temperature of 85°F. This temperature, somewhat lower than anticipated, accounted for a temperature differential of only 15°F rather than the design differential of 28°F.

INTERIOR FURNISHINGS AND EQUIPMENT

The bow section was utilized for storage shelving and space for one CO_2 scrubber. This shelving was perforated to allow for free circulation and mixing of gases. Triple pipe berths were located port and starboard, just aft of the bow section, with expanded-metal storage baskets located outboard of each berth. Curtains provided privacy for the sleeping area. Just aft of the sleeping area, on the port side, is a counter which extends aft to a partial bulkhead.

This counter provided a laboratory work space, sink, and cooking area. A rotisserie and hot plate are provided for cooking. Underneath the counter were cabinets for the storage of medical supplies and equipment, eating utensils, a thermoelectric refrigerator, and a 20-gallon electric water heater. Two deadlights were located above this counter. A mess table was located on the starboard side aft of the sleeping area. This table was flanked by two deadlights. Folding chairs were provided for seating. Mounted to the partial bulkhead on the starboard side was a gas-monitor bench. A marine toilet and shower were located on the port side aft of the partial bulkhead. A 40-gallon emergency fresh-water tank was installed outboard of the shower. A lavatory was provided on the partial bulkhead, starboard side, and hanging space for the divers' wet suits was available also on the starboard side aft of the lavatory. The entrance trunk was located on the hull center line and was tied into the full bulkhead between the He-O_2 and air spaces. The decking, 1/8-in. plate, was approximately 18 in. above the hull bottom and was approximately 6-1/2 ft wide. A 1/2-in. gap was left all around the deck perimeter to provide for bilge ventilation. Below-deck space forward of the partial bulkhead was used as storage for eight 200-cu-ft bottles of oxygen and four 200-cu-ft bottles of helium. This gas was included as emergency supplies. The partial bulkhead was watertight below decks to contain any water from the shower, lavatory, and wet suits in the head area. A drain hole for this area was provided in the forward side of the entrance trunk. Two drain holes, one aft of the bow section and one forward of the partial bulkhead, were provided for draining any condensate from that section.

DEHUMIDIFIERS

Three 28-pint-per-day capacity dehumidifiers (rated at standard atmospheric conditions) were installed. Two of these were installed overhead in the partial bulkhead in the He-O_2 space. These were installed so as to take in the damp air from the head and trunk area and to discharge dry air forward into the living space. One unit was mounted in the air space, starboard side, so as to take in damp air from the trunk area and to discharge around the power transformers.

GAS SYSTEMS

Oxygen supplies were contained in three 1300-cu-ft bottles located beneath the hull. The oxygen was piped into the Sealab air space through 3/16-in. I.D. Teflon-wire braid high-pressure hose. One-quarter inch, schedule 80, CRES pipe was utilized inside the Sealab to convey the oxygen from the air space into the He-O_2 space and the flow-monitoring system. Valving was provided to control flow from both the air space and the He-O_2 space. The flow-monitoring system consisted of two 200-cu-ft oxygen bottles, a pressure reducer, and necessary valving. In operation, oxygen quantity would be determined by pressurizing the known volume (200 or 400 cu ft) to the required pressure. This volume would then be bled slowly into the Sealab atmosphere.

Part of the emergency helium supply was contained in one 1300-cu-ft bottle beneath the Sealab and was conveyed into and distributed in the Sealab through a system similar to the oxygen system. Flow measurement was not required in this case, since the He would merely be bled in to control internal pressure, i.e., water level in the He-O_2 entrance trunk.

The normal helium make-up gas was to be supplied through a hose in the umbilical cord from the surface. This hose was connected to the Sealab helium system in the air space. An air-supply system was provided for the air space, with provisions for supplying emergency air to the He-O_2 space. It was anticipated that air might be required in the He-O_2 space for blowdown in case of contamination of the He-O_2 atmosphere or flooding of the compartment. Air was supplied to the system through 1100 ft of diver hose in the umbilical cord.

FRESH WATER AND SANITARY SYSTEM

The fresh-water system was conventional in design and supplied water to the sink, lavatory, commode, water heater, and shower. A 40-gal emergency storage tank was provided

but was not piped into the system. Filling of this tank was accomplished by the use of a short length of garden hose. Water was supplied through 1100 ft of 1/2-in.-inside-diameter vinyl garden hose in the umbilical cord. The sanitary drain system was conventional, with some innovation. All fixtures were trapped, and a single vent was installed. Since the system could not be vented externally, the vent was installed adjacent to the commode, and a charcoal filter was installed to remove odors. The external drain was fitted with a 2-1/2-in.-diameter rubber hose in order to keep the sea-water outlet below the bottom end of the He-O_2 entrance trunk. This expedient was necessary to prevent loss of atmosphere through the normally open drain system. It was anticipated that stoppage in the external drain hose might be caused by floating sewage. In order to cope with this problem, a hose bibb was installed in the drain line outboard of the sea cock. This device would allow for positive blowdown of the external opening by closing the sea cock and attaching a portable bilge pump to the hose bibb.

ELECTRICAL SYSTEM

A 120-volt, three-phase, ungrounded electrical distribution system was used to supply power for lighting, heat, and other electrical equipment. The 120-volt, three-phase power was obtained from a 450-to-120-volt, three-phase transformer bank in the air space. The 450-volt, three-phase power was supplied to the transformer bank through 275 MCM three-conductor cable in the umbilical cord. The transformer bank consisted of three single-phase, 450-to-120-volt, 25 kva, naval shipboard, dry-type transformers connected delta-delta. This system was selected to permit continued operation at reduced capacity in the event one of the transformers failed. The 75-kva transformer capacity was based on an anticipated 20-kw heat load and a 14-kw diving-light load. A breakdown of load capacity provided is shown in Table A1.

Table A1
Details of Sealab Electrical System

Sealab Space	Load	Power (Watts)
He-O_2	Lighting	1000
	Dehumidifiers (2)	1800
(Living quarters)	Air pumps (2)	3600
	Sump pump	1200
	Water heater	1250
	Refrigerator	1000
	Cooking	3000
	Heat	9700
	Electric blankets	1200
	CO_2 scrubbers (2)	1500
	General-purpose outlets	6000
	Total	31,250
Transformer	Diving lights	15,000
room (air space)	Dehumidifier (1)	900
	Lighting	100
	Heat	1,250
	General-purpose outlets	3,000
	Total	20,250

A terminal box was installed above the transformer bank to facilitate connecting the power-supply cable to the primary of the transformers. Two 200-amp commercial type three-pole circuit breakers were installed on the overhead above the transformers as main disconnects for the 200-amp, three-phase power-distribution panels. Distribution panel 1 was installed in the He-O_2 space and provided power distribution for heat, lighting, convenience outlets, dehumidifiers, and other electrical equipment installed in the compartment. Distribution panel 2

was located in the air space and provided power distribution for the diving-light load, lighting, heat, convenience outlets and dehumidifier.

The branch circuits were controlled from the distribution panels with two-pole circuit breakers. Electrical metallic tubing, used for all branch-circuit runs, was installed on the surface of the insulation. Commercial type TW wire was used in all conduit runs. Standard commercial type fittings, boxes, and devices were used except in areas subject to water splash, in which case Navy type SBM switches and receptacles were used. All receptacles used were the grounded type, and all portable equipment not provided with grounded type plugs were fitted with three-conductor cords and standard grounded plugs.

Four 1250-watt ceiling-type electric radiant heaters and one 1500-watt bulkhead-type forced-air electric heater were installed in the He-O_2 space. One 1250-watt ceiling-type electric radiant heater was installed in the air space. Two portable 1600-watt heaters were provided for additional heat if required.

Enclosed type marine lighting fixtures were used. Light bulbs were tested to determine their ability to withstand the high external pressure to which they would be subjected. Standard 100-watt bulbs broke at a pressure equivalent to a depth of 150 ft, 60-watt bulbs broke at 375 ft, and 40 watt bulbs at 416 ft. Fifty-watt rough-service and 40-watt appliance bulbs withstood a pressure equivalent to a depth of 800 ft without breaking. Forty-watt appliance bulbs and 75-watt and 50-watt rough-service bulbs were selected for use.

The 1100-ft power-supply cable was made from a surplus buoyant minesweeping cable. The cable consisted of three insulated 275 MCM aluminum conductors fitted with 3-in. cylindrical floats, except for 175 ft of the inboard end and approximately 20 ft on the Sealab end. Three terminal lugs were installed on the Sealab end of the cable and taped with several layers of self-vulcanizing tape to prevent air from leaking up the cable. Prior to installing the lugs, the tapered part of the barrel of each lug was filled with epoxy resin to prevent air from leaking through the end of the lug. The inboard ends were connected to a terminal box on the YFNB-12 which was fed from 60-kw, 450-volt, three-phase diesel-driven generators.

COMMUNICATION SYSTEM

Communication between the Sealab and the control center on the YFNB-12 was through a multiconductor cable in the umbilical cord. The communication cable contained three 75-ohm conductors, six No. 20 AWG copper conductors, and nine No. 22 AWG copper conductors. Plugs were installed on each end of the cable to facilitate connecting the cable to the junction boxes in the control center and in the air space of the Sealab. The connector on the Sealab end of the cable was potted to prevent air from leaking up the cable. A receptacle was mounted on each junction box to receive the cable plug. From the junction box in the air space, ten conductors and one coax conductor were extended through the gas-tight bulkhead and terminated in a junction box in He-O_2 space.

In the He-O_2 space, circuits were provided for a calibrated microphone, an electrowriter, a diving phone, and a telegraph key. In the air space circuits were provided for a diving phone and a TV camera. There were four spare conductors in the He-O_2 space and five spare conductors in the air space.

The communication cable was made from a surplus buoyant mine-hunting cable. The cable jacket was surrounded by a double flat braided basket-weave armor, and a second jacket of foamed polyethylene covers the armor.

A section of old XN-3 cable was prepared for use with a GE television camera to be located in the He-O_2 space. However, the coax of this cable became defective, and it was also found that the camera controls could not be operated remotely through 1100 ft of this cable. The camera control was then installed in the He-O_2 space, and the video signal was transmitted through the spare coax in the communication cable. The spare coax conductor terminated in the air space; therefore, a jumper cable from the air space to He-O_2 space through the trunk access was used. A Navy type MSS-6 cable was installed into the He-O_2 space for voice communications on the Applied Science Lab speech unscrambler.

APPENDIX B

LIFE SUPPORT

GAS MONITORING

Critical to the well-being of the aquanauts was the established system of gas monitoring employed in this project. Since meticulous control was required to maintain oxygen levels yielding the desired partial pressures of 200 to 210 mm Hg, and carbon dioxide levels below 0.2 percent, the monitoring instruments in Sealab I and in the control shack topside alike were selected with considerable care. Within Sealab, chemical and battery-powered devices were utilized for O_2 and CO_2 determinations. Selection of these instruments was predicted on a long series of tests in a synthetic atmosphere, under seven atmospheres of pressure.

Topside, an air-conditioned house trailer served as a gas monitor and control shack. This trailer, air-conditioned to assure instrument fidelity, received a continuous stream of gas sampled from the atmosphere of Sealab I, via the umbilical tube. Through a multiple manifold system, it was possible to pass this gas flow through an array of instruments for continuous analysis. By utilizing standard oxygen-analysis equipment, carbon dioxide analyzers, and a Perkin-Elmer fractometer for recording and analysis of nitrogen, helium, and oxygen, it was possible to maintain a continuous watch over the breathable atmosphere of Sealab I. In addition, a battery of Mine Safety Appliances and Kittigawa gas-sampling tubes were used to spot-check a range of almost 20 potentially toxic gases.

Carbon dioxide control inside Sealab was achieved through use of two lithium hydroxide-charged scrubbers, each containing a load of about 18 lb of reagent. Efficiency of these units proved excellent, under conditions of the experiment; recharging at three-day intervals was adequate for safe control of carbon dioxide levels within Sealab.

GAS SUPPLY

Monitoring of the gas composition revealed that the nitrogen percentage steadily decreased, due to solution in the sea water. It became possible to use compressed air for makeup of oxygen usage, since the nitrogen was absorbed about four times as fast as oxygen. No appreciable loss of helium was noted during the course of the operation.

DEHUMIDIFICATION

The installed dehumidifiers worked at near rated capacity, removing about six gallons per day of water from the $He\text{-}O_2$ space, and humidity was controlled at near 72 percent. Contributory factors to the occasional rise were open water surface in the entrance trunk, hot showers on completion of excursions, wet suits hung up, and moisture in exhaled breath.

THERMAL CONTROL

Much less heat was required to maintain comfort than had been predicted. The cork insulation in the $He\text{-}O_2$ space re-expanded to its initial 1-in. thickness within a few hours on the bottom, while that in the air space became compressed on the way down and never did re-expand. This difference is due to the increased diffusion rate of helium over that of nitrogen.

WET SUITS

The wet suits which went down "dry" in Sealab quickly re-expanded to their original thickness. Those worn down by the subjects did not re-expand during the experiment. The reason for this difference is unknown. Protection provided by even the re-expanded suits was inadequate to take full advantage of the time available for working excursions.

HOOKAH EQUIPMENT

Equipment used to pump the Sealab atmosphere to and from a swimmer failed to perform satisfactorily. The gas pumps were noisy and overloaded, and had to be placed two in series to provide enough gas to support one swimmer. This concept is very attractive, but the present equipment is inadequate.

APPENDIX C

SUPPORT SYSTEMS

BARGE

The principal support vessel for Sealab I was the large covered lighter, YFNB-12. Originally built in 1945, this craft has undergone several extensive modifications for participation in various research projects. She was selected as the support vessel because she was available, and she comes as close to meeting the multitudinous requirements for a surface-support vessel as any (power, compressed air, heavy winches, clear deck space).

The YFNB-12 is 268 ft long, has a 48-ft beam, a flat bottom, and a displacement of 3000 tons. She is non-self-propelled, although she has four 250-hp Murray and Tregurtha harbormaster units mounted on the fantail, which give her some limited mobility. Her outstanding characteristics for this project are: a heavy monorail cantilevered out over the stern which permits handling heavy objects in the water astern, a Maniwotoc 60-ton crane mounted forward, and a rather generous amount of clear deck space for laying out equipment and conducting operations. She carried a large biaxial (automatic fleeting) winch (100,000-lb pull capacity) amidships, a pair of LST stern anchor winches on the fantail, and a conventional anchor windlass with capstan on the bow. Already installed were a pair of electrically driven 31,000-lb, 20-CFH air compressors with an accumulator bank of 90 cu ft, and filters to permit use as breathing air; and a pair of 100-cfm, 110-psi gas-driven Joy low-pressure air compressors. The electrical system on the barge was not used for Sealab support.

This vessel suffers from the major disadvantage that it reacts very actively to an ocean swell; i.e., it behaves much like a cork in response to long waves, and in any sort of chop, has a snappy 4-3/4-second roll which can make use of the crane difficult at sea. Other than this, she is reasonably well suited to support of this type of unorthodox operation. Her shop facilities are adequate; storage of bulky equipment (gas bottles, diving gear, etc.) is easily handled, and berthing facilities, although certainly not luxurious, can be readily expanded to accommodate 40 or 50 additional personnel for such a project.

ANCILLARY FACILITIES

Major equipment which was added to the barge specifically for support of Sealab is as follows:

1. A double-lock Dixie recompression chamber for support of surface (conventional) diving personnel in the event of a bends case – A second Dixie chamber hull which was on board was tied into the low-pressure air system for use as a large (200-cu-ft water volume) accumulator. This second Dixie chamber could have been readied for use in treating a bends case on short notice had it been needed.

2. Hydraulic ram high-pressure gas pump – The diving requirements of this project called for large amounts of helium-oxygen mixtures and some helium-air mix. In order to refrain from wasting large amounts of gas in cascading, and to permit easy "jamming" of scuba bottles to 3000 psi, it was necessary to obtain a high-pressure, oil-free gas pump. It was determined that the simplest approach would be to build a rather unconventional hydraulic system using high-pressure air to force water into a cylinder containing the gas to be compressed. This system worked quite well, although it can be seen that it would use a great deal of high-pressure air. Since air is a relatively cheap commodity, it would seem that this pump is a fairly adequate method of pumping diving gases, and might appeal to others faced with similar problems.

3. Control center – A 40-ft trailer (formerly used as a bunkhouse for workmen) was loaded onto the barge to serve as the control center for the Sealab. Thus all communications, physiological monitoring, TV, and gas sampling was done in this single, air-conditioned area partially separated from the test of the activity on the barge. This philosophy of providing a semi-isolated, quiet space for a control center worked out very well, and is highly recommended over attempts to utilize shipboard compartments for this purpose.

4. Electrical supply – Two GM 671 60-kw, 440-volt diesel generators were installed with their own switchboard on the top deck to supply power for Sealab and the control center. Thus the project was not dependent on the barge's electrical system, although a tie switch permitted feeding the switchboard from the YFNB-12 440-volt bus in the unlikely event of failure of both generators. Power usage by Sealab is discussed in Appendix A.

5. Submersible decompression chamber – A single-lock steel decompression chamber was mounted in a steel framework which would hold sufficient lead ballast to sink it and which would permit handling by the crane for lifting out of the water. This chamber was supplied with air, lighting, and communications via its own umbilical cord to the surface. It was used for two purposes: first, as a diving bell, open end down, for use by surface divers in descending and ascending in order to conserve the gas in their scuba tanks (the trip down and the ascent, with its decompression stops, are made breathing the air supplied from the surface, rather than the limited self-contained supply); and second, as the primary means of emergency escape for the Sealab subjects if unforeseen events should require immediate evacuation of the Sealab. In this mode of operation, the subjects would enter the SDC, close the entry hatch, and be hoisted to the surface and on deck while still under pressure inside the SDC. The pressure would then be lowered in accordance with decompression requirements in returning the subjects to an atmospheric environment. A small (17 × 21 in.) so-called "medical" lock in one end of the chamber permits food and supplies to be passed into the chamber, and wastes to be removed. The chamber itself, only five feet in diameter by 10 ft long, would be cramped quarters indeed for four men during the 30 to 40 hours that would be required for decompression, but would certainly be bearable, and as such it provided an adequate emergency escape system. The chamber, framework, and ballast weigh about 6-1/2 tons (in air), and thus constituted somewhat of a handling problem. A smaller volume would be highly undesirable, however, since the crowding problem would be severe if the chamber had to be used for Sealab evacuation. The ideal solution, of course, would be a small, easily handled chamber which could be married to a fairly spacious surface unit. Thus the small chamber would be used only for transportation to and from the bottom, and crowding would be no problem. The surface unit would be fitted with atmosphere-purification equipment to permit use of a captive mixed-gas environment; dehumidification equipment to improve comfort; a personnel lock to permit assistance by outside personnel in the event of a casualty; and numerous other improvements that are difficult if not impossible to build into a submersible unit.

6. Communication systems – Communications between the submerged habitat and the surface tender consisted of several links: closed-circuit TV, divers' telephone, electrowriter, telegraph key, and a voice circuit modified with a "speech unscrambler" to improve the intelligibility of speech in this high-helium-content atmosphere. Two of these, the electrowriter and the speech unscrambler, are of sufficient interest to bear further description.

a. The electrowriter is a device which transmits, via wire, the lateral and transverse components of motion of a stylus, and reproduces these movements at a remote location to produce a facsimile of whatever was written or drawn with the original stylus. A one-way system was installed for Sealab I, with the transmitter in the habitat and the receiver only in the control center. This device proved to be extremely useful for conveying information best displayed as diagrams or sketches, and would have been equally valuable in other directions. These units are commercially available, and are widely used in industrial applications.

b. The difficulty of communicating with a diver breathing a helium-oxygen mixture has been apparent for quite some time, and has caused a great deal of inconvenience in previous pressure-chamber experiments in long-duration exposure. The difficulty arises primarily from the fact that the increased velocity of sound in this medium causes the cavities of the nose and throat to resonate at higher frequencies, thus giving many of the speech sounds a

"squeaky" effect. This shift of frequency of the speech sounds is, of course, quite nonlinear, with the amount of shift being greatly dependent on the character and method of formation of the particular sound. For example, the pure vowels are greatly affected by the resonant characteristics of the vocal cavities, while the unvoiced consonants (as for instance, the "sss" sound in the word "hiss"), produced by passing air over sharp edges or through small openings in the mouth, seem to be affected differently by the presence of a helium atmosphere. The U.S. Navy Applied Science Laboratory designed a device which, in an attempt to improve the intelligibility of this helium speech, filters out all frequencies below 1000 cps and above 3000 cps and discards them; then it takes the remaining speech components between 1000 and 3000 cps and, by a heterodyning process, shifts them uniformly downward by about 450 cps. The resultant speech is perfectly satisfactory for communications, seeming to contain most of the intelligence, even though the shift completely ignores the nonlinearity of the distortions present. Inasmuch as the intelligibility problem becomes worse with increasing depth (pressure), it is likely that this technique will need to be sophisticated somewhat for greater depths.

APPENDIX D

PHYSIOLOGICAL AND PSYCHOLOGICAL ASPECTS OF SEALAB I

PHYSIOLOGICAL EFFECTS

The physiological aspects of project Sealab I presented no serious problems. Although some new and unexpected facets were uncovered, these are amenable to laboratory study, and offer no real bar to extensions of the Sealab concept. Perhaps the most important medical finding of the project was the fact that, for many years to come, all such undersea manned ventures will require improved coordination of medical and engineering phases of the program, with a great degree of control vested in the medical complement of the operation team. It must be clearly recognized that, as in the case of deep-submarine escape, exposure of man to high pressures is now, and for some time to come will be, a problem requiring close medical attention. Engineering problems of system design, handling of the complex at sea, etc., are considerable; but all such problems are interrelated with potential physiological disasters, and must therefore be considered in light of the peculiar medical requirements of the experiment.

In the course of the Sealab experiment, more than 30 physiological values were derived daily from each subject. These bits of information, covering all useful parameters of blood morphology, blood chemistry, basal metabolic function, body temperature, and general physiological status, gave no evidence of measurable changes in the overall health of any of the underwater subjects. The studies covered, in all cases, a baseline study of five days of sea-level medical data, prior to the experiment, and an equal span of time after the undersea exposure.

Two medical findings are of considerable importance. First, the subjects of Sealab I demonstrated an ability to acclimatize to the temperature losses inherent in He-O_2 living and working in ocean water. Second, there appeared to be a clearly defined slowing of all physiological functions, under conditions of an undersea environment. The first finding is of importance, since evidence from previous experiments promoted the belief that an environmental temperature of 91°F would be required for normal body comfort. In Sealab I, however, it was found that ambient temperature could be reduced to 84°F after four days of gradual acclimatization. Although this finding does not dismiss the problem of human heat loss, it offers at least a second look at the range of human adaptation, and improved design of the submerged habitat. The second finding will be discussed in a subsequent section of this appendix.

ATMOSPHERIC EFFECTS

The atmosphere for the Sealab I habitation had been preselected at 79 percent helium, 17 percent nitrogen, and 4 percent oxygen. Generally speaking, an attempt was made to adhere to these values. New findings, however, dictated some departures from this set formula. Early in the course of the experiment, a steady drop in nitrogen values was noted, although the phenomenon could not readily be explained. Helium and oxygen levels, however, remained at anticipated values, with no makeup required for the former gas, and normal utilization of the latter. In addition, it was noted that the requirement for CO_2 removal in Sealab I was drastically reduced, as compared with previous controlled experiments in pressure chambers. Since basal metabolism of the aquanauts remained normal, it was evident that some new factor was active in CO_2 removal.

As a best possible explanation, it was concluded that the small area of sea water exposed in the entrance trunk was serving to absorb considerable quantities of both nitrogen and carbon dioxide. At first glance, this explanation may seem improbable, but certain physical factors must be acknowledged. First, the solubility of CO_2 in sea water is extremely high — about

30 times that of oxygen; and secondly, the partial pressure of both CO_2 and nitrogen inside Sealab I, as compared with those in the ambient sea water, were such as to create a favorable gradient for solution of both gases. Helium, being relatively insoluble, would not be taken up in appreciable amounts, which would explain its stability.

This educated guess must await further laboratory experiments for confirmation; but it would appear that ambient sea-water scrubbing might be incorporated into the design of future undersea habitats. In the case of Sealab I, it was found possible to utilize no more than regular additions of compressed air to meet the requirements of the aquanauts. In this manner, the desired oxygen levels were attained, and the excess nitrogen was soon dissolved in sea water, and thus eliminated. Thereby, stored-oxygen requirements were drastically reduced, and atmosphere control simplified.

Of physiological importance, it was noted that when oxygen levels were held at four percent, or in excess, the aquanauts reported an improved sense of well-being, whereas when levels of three to three and one-half percent obtained, this was not the case. For this reason, and although electrocardiographic records showed no hypoxia of cardiac muscle at the lower levels, oxygen levels in Sealab I were maintained above four percent (26 percent effective), for most of the exposure. Obviously, this observation must be checked out in the laboratory; but it seems probable that the increased atmospheric density (approximately 1.6 times greater than sea-level air) may sufficiently impair pulmonary ventilation to require added molecular concentration of oxygen.

A final matter of importance in atmosphere control must be considered. In Sealab I design, a compressed-air compartment was included, in anticipation of speech difficulties due to helium, and to provide isolation for the high-voltage transformers, which might be a potential source of fire and toxic gases. This compartment, charged with compressed air at the equivalent depth of 186 ft of sea water, was also used for stowage of scuba gear; consequently, the "air compartment" was occupied on frequent occasions by the aquanauts, who came directly from the helium-oxygen atmosphere of the living compartment.

Within the first 24 hours of exposure, it became apparent that, after denitrogenation in the Sealab $He\text{-}O_2$ atmosphere, exposure to compressed air resulted in an immediate and dangerous level of nitrogen narcosis. Briefly, the effect of a visit to the compressed-air space was equivalent in narcotic impact to a 350-ft exposure in an air-filled recompression chamber. Once this hazard was recognized, the atmosphere was diluted with helium, and the problem resolved. Nevertheless, it would seem that, once the human body is largely denitrogenated, susceptibility to nitrogen narcosis is significantly increased, perhaps out of proportion to the involved partial pressures of the gas. Laboratory experiments will undoubtedly clarify this issue; but it is important to note that exposure of future aquanauts to compressed air might be unwise.

HEMATOLOGICAL EFFECTS

Blood studies performed on Sealab I subjects included a condensed range of blood-chemistry values, together with a routine daily examination of all formed blood elements (morphology). In all cases, adequate baseline determinations were made over the course of several months prior to the actual experiment, with increasingly repetitive studies done at Kindley AFB in the days prior to submergence. During the period of undersea exposure, blood samples were run daily in the laboratory on board YFNB-12, with matching samples sent to Kindley laboratories for continuity and comparison. Although a significant degree of hemolysis was encountered in all collected blood, this was a uniform phenomenon, and did not materially affect the validity of the results.

It should be added that, for a five-day period following the experiment, all subjects were re-examined at the Kindley AFB facility, and a permanent record made of all physical and laboratory findings. This follow-up baseline was included in the overall physiological evaluation of the experiment.

Blood-chemistry determinations included all blood electrolytes, blood-sugar values, blood-urea nitrogen and nonprotein nitrogen levels, and plasma CO_2 determinations. In no case was a significant deviation from normal noted in any of the four subjects. Since previous experience in equivalent chamber exposures demonstrated that all blood chemical values remained exceptionally stable after the ninth day of exposure, it is reasonable to assume that the normal values evident in the Sealab I experiment would have been maintained had the total exposure time been extended many more days.

Blood morphological values, obtained daily, included differential counts, white and red cell counts, sedimentation rates, hematocrits, and reticulocyte determinations. Special attention was directed to any morphological evidence of immature or otherwise abnormal blood elements. Standard techniques, similar to those of previous chamber exposures, were used throughout. Save for a single occasion on which excessive hemolysis resulted in abnormally low hematocrits in all subjects, the results were uniformly within normal limits. Despite daily acquisition of 40 cc or more of blood from each subject, reticulocyte counts remained normal, and hematocrit and hemoglobin values were steadily maintained.

In light of the unhappy experience of Cousteau's group, where a moderately severe anemia was discovered after prolonged exposure to compressed air at only 32 ft of sea-water depth, it was gratifying to find no overall hematologic disorders in the Sealab I personnel. Almost certainly, success in this respect can be attributed to the fact that, during the "bottom" phase of the experiment, oxygen partial-pressure values were rigidly maintained below 210 mm Hg, which may be close to the borderline of prolonged physiological tolerance to this gas.

Generally speaking, it may be said that no adverse hematological results were noted during or after the Sealab I human exposure; and although detailed analyses of data have not been completed, the results are currently quite reassuring.

LATE EFFECTS

In human exposure to many altered parameters, as were found in Sealab I, it is necessary to be especially alert for delayed adverse effects with respect to any and all organ and skeletal systems. Accordingly, a rigid follow-up program was established for the subjects. Following the initial five-day post-run study series, the aquanauts are to be given an identical physiological investigation at intervals of one, three, nine, and 18 months. At the completion of the Sealab I project, however, one aquanaut had been a subject in chamber exposures for almost two years, and another for 18 months, with similar follow ups, without evidence of pathology.

To date, including all subjects regardless of exposure time, no evidence exists of present or potential damage to skeletal or organic systems. Examinations in support of this statement include special inspection of the lens of the eye and long-bone and joint x-ray surveys, in addition to the complete battery of physiologic tests normally employed. In consideration of the fact that most, if not all, latent adverse findings should be demonstrable within this time, it does not seem likely that the future series of examinations will disclose pathological conditions related to the Sealab I experiment.

SUMMARY OF PHYSIOLOGICAL EFFECTS

In conclusion, it may be said that, insofar as preliminary inspection of data reveals, no adverse physiologic effects have been noted as a result of the aquanaut exposure to the experimental conditions of Sealab I project. This is not to say that no questions were raised; on the contrary, many basic factors of life in an exotic atmosphere and under high pressures are poorly understood, and require intensive future laboratory investigation.

It is probable, for instance, that the principal investigator and his assistants erred in the direction of safety and known parameters, in order that no failure should occur. Thus, decompression schedules may have been ultraconservative, gas composition unimaginative, and work schedules in the "hostile" environment of the ocean, restrictive. Given more succinct

knowledge, a more streamlined and productive schedule might be planned for the next aquanautic venture. Be that as it may, a cautious appr ach, with basic laboratory confirmation, seems the wisest course. In such a manner is likely that the needs, not only of a Sealab program, but probably of connected and equally important undersea ventures, may best be met.

Finally, as a result of Sealab I and preceding experiments, it is evident that man has an undetermined but vast capability of adaptation to hostile and exotic environments, without apparent physiological ill effect. Acclimatization to abnormal temperature differentials has been demonstrated, within limits, and ability to survive and function normally in a synthetic breathing medium is now a matter of fact.

Additional questions regarding physiological status quo at much greater depths must await combined investigation in the field and in the laboratory. A successful probe has been accomplished; but operational ventures must not outstrip basic laboratory support.

PSYCHOLOGICAL EFFECTS

Although any report of psychological findings in this experiment must be considered incomplete and premature, some early observations are worthy of note.

First, the question of group cohesion and interpersonal effectiveness is important to any future plans for the Sealab concept. In the case of Sealab I, subjects were selected on the basis of individual capabilities and known physiological profile, without respect to possible psychological incompatibilities. Involved were four persons whose academic training ranged from one with a medical degree plus some postgraduate training, to the lowest-rated member of the team, with less than a high-school training equivalent. Socially, the order of the group covered this same extreme range, with the two Chief Petty Officers again midway, and about equally balanced. Personalities, broadly speaking, ranged from a total extrovert to an extremely sensitive introvert. Motivationally, it would be fair to state that each subject was driven for success of the program at about the same level, but probably for different personal reasons. In terms of reward, little difference existed, materially. For all four subjects, the immediate environmental pleasures and hazards were essentially the same.

Group cohesion and general effectiveness of interaction was remarkably good, considering the spectrum of personalities and talents involved. Almost predictably, each subject with a specialty took control of his particular phase of the operation; and, with a few exceptions, this alternation of operational authority was accepted. Throughout the experiment, foul language served to replace actual interpersonal conflicts, since this speech modality need not be directed to any one person, save in the mind of the speaker. Generally speaking, vulgarity was an effective device for promotion of group activity without demonstration of individual resentment. When supplementation was required, a group verbal assault on the topside control served useful purpose, and was occasionally employed.

A second observation, and possibly of considerable importance, is the fact that subjects of Sealab I, from the moment of their entry into the pressurized habitat, moved at about half speed. This observation, made in previous pressure-chamber exposures, and supplemented by similar notations in all of Cousteau's experiments, deserves further attention. The slow-motion activity, which persisted in lessening degree for four days in all cases, requires explanation. Psychologically, the subjects might be reacting as animals to a strange but undefined environmental hazard. In such a situation, the animal moves with extreme caution, and inchwise. Physiologically, this effect may represent the impact of a completely new environment on the organism, with general slowing of all metabolic functions such as were observed. Finally, however, the reaction may represent no more than an observation of the fact that, working outside in a medium almost 800 times denser than air, the slowest approach is the most successful. The answer, obviously, awaits further laboratory and field investigation.

The significant point, however, cannot be disregarded. In any phase of the man-in-the-sea project involving exposure to high ambient pressures and intermittent sorties into the marine environment, man cannot be expected to perform with efficiency such as might obtain in a

sea-level, dry-land. situation. In considering task-performance capabilities, therefore, this underwater restriction must be taken into account. Despite the fact that, after completion of the initial four-day period, activity levels increased, there is no reason to believe that total performance as measured in output-hours can be expected to reach sea-level norms.

Finally, the interrelationship of submerged operations and topside control deserves consideration. In earlier chamber experiments, the subjects were to some degree self-dependent. Nevertheless, the chamber occupants were at all times aware that outside investigators controlled their breathing atmosphere, communications, and internal pressure of the habitat. Thus, to a large degree, the subjects were dependent on the skills and scientific resources of the principal investigator and his assistants. Accordingly, most of the subject demands were of a minor nature, and no suggestions were ever made concerning environmental control of the experimental situation.

Such was not the case in Sealab I. Here, the aquanauts had been assured that they could easily survive for many weeks without assistance from the support vessel or from the principal investigator. After a few days of tentative probes, the subjects became convinced of this fact, and abruptly developed a great sense of independence. Within a short span of time, the aquanauts sought, psychologically, to cut the umbilical cord to the surface-support vessel and to the Sealab control operators. This became manifest in many ways, e.g., trying to dictate optimum gas mixtures; demanding unreasonable surface support; and informing topside control that they could do without us for an infinite period of time. Such a view, while understandable, does not increase rapport between investigator and subject, and leads to a dangerously carefree attitude on the part of the aquanauts. Such was the case in the latter days of the experiment, when Manning lost consciousness on the ocean bottom.

Briefly, this accident occurred in the course of a complex operation which required scattered location of three aquanauts on the ocean floor around Sealab I. Partly in response to the autonomous tasks involved, and in keeping with the dangerous spirit of independence previously described, no "buddy" system was followed, and each aquanaut emerged from Sealab I without an independent check of his breathing apparatus. Manning donned a Mk VI semiclosed circuit apparatus which subsequently ceased to deliver adequate amounts of breathing mixture. After nearly ten minutes outside, he became aware of impending disaster. He attempted to return to the safety of Sealab I, but passed out immediately under the entrance hatch. He was discovered by the inside watch, and quickly resuscitated, with minimal residual effects.

Soon after this near fatality, a spontaneous reappraisal of attitudes was accomplished by the aquanauts. "Buddy" systems were re-established; authority of the senior diver was affirmed; and, by unanimous consent, topside control was thereafter acknowledged.

SUMMARY OF PSYCHOLOGICAL EFFECTS

In summary, the psychological aspects of the Sealab I project offered no really serious problems. Certain areas are sufficiently provocative to require further scientific investigation. It is, for example, certain that time-motion studies should be pursued in future exposures, since this is clearly a problem in all proposed man-in-the-sea activities. Likewise, definition of group size and makeup is of importance, but this definition must be made in light of the tasks to be performed, rather than on the basis of meticulous matching of personalities. Finally, it is important that clear-cut lines of command be established prior to any underwater adventure, so that no confusion of authority be conveyed to the exposed subjects.

The nature of exposure of the aquanaut required a special type of motivation. This motivation is an emotional drive which is poorly understood by psychological investigators, who have never been exposed to an undersea situation. In the ultimate analysis, motivation for the job is the critical and deciding factor, in such an operation as Sealab I.

APPENDIX E

OPERATION SEALAB I LOG

JULY 20, 1964
ON DUTY: CAPT BOND

Operation Sealab officially got underway at 1735 today, when GM1 Anderson left the Submersible Decompression Chamber (SDC) at the 165-ft level and skin-dove to Sealab I, entering the He-O_2 space at abovementioned time, and singing "O Sole Mio" in helium speech. Within five minutes, he was joined, in order, by LCDR Thompson, HMC Manning, and QMC Barth.

Situation report on arrival was as follows: atmosphere satisfactory; temperature 74°F and chilly; all electrical fixtures except the hot-water heater and refrigerator functioning properly; Sealab dry and habitable. No fresh water on the line, and TV monitor not properly hooked up.

Two heaters were put on the line; air was evacuated from the water line after opening valve topside, and fresh-water flow established, with return function of hot-water heater. TV monitor was connected, with a clear image. The CO_2 scrubber was turned on, and some LiOH dusting was noted, but corrected. Electrowriter was in commission, and clear messages obtained. Depth gauge read 186 ft of sea water. Calibrated microphones could not be made functional, will be returned tomorrow for topside repair. Krasberg O_2 meter showed 30 percent equivalent oxygen, vs 28 percent equivalent by topside monitoring. CO_2 less than 0.1 percent. Inside temperature at 83°F and comfortable, after one hour of heater operation. Cut to one heater.

At about 1900, Anderson and Barth went to work in the air space and outside Sealab I, opening sanitary drains, and testing gas lines in the habitat. The sanitary drain was opened, and the drain line connected. In the air space, all gas connections were checked and found intact and normal except the helium input through the umbilical, through which gas could not be forced yesterday. After inspection, Anderson discovered that the check valve in the line had been reversed on installation. This discrepancy was corrected, and the line tested okay.

Situation report at 2200 hours:

Watch bill set: one man awake, other three asleep! Atmosphere: 4.2% O_2, 16.8% N_2, 79% He, humidity "very dry"; temperature 84°F and comfortable. Port between compartments replaced. Subjects happy; all systems go. Operation Sealab I is off to a good start!

JULY 21, 1964
ON DUTY: CAPT MAZZONE

At 2400, added first oxygen; 67.3 liters were bled in at a rate of five liters per minute.

At 0130, CO_2 by Dwyer was 0.3%. Scrubbers turned on. Scrubbers reported as very noisy.

With lights turned down in Sealab, the subjects made several observations of undersea life – the abundance of fish and apparently the size of some fish were more than expected. Subjects hope to train some.

At 0200, scrubber secured. CO_2 less than 0.1%; temperature is 86°F; humidity reported as very good; Sealab quite comfortable.

WB - 84°F (Wet Bulb)
DB - 87°F (Dry Bulb)

Krasberg unit - 5.8 × 5 - 29% effective. Fractometer - very close to 29% effective.

At 0400, scrubbers on for 15 minutes.

JULY 21, 1964, 0500
ON DUTY: CAPT BOND

Assumed the watch at 0500 from CAPT Mazzone. Subjects quiet, atmospheric conditions satisfactory. Topside sea state calm, small swells, no winds. TV monitor is adequate with low level illumination.

At 0600, Barth on watch, reported 5 in. water above bilge drain; permission requested to add makeup helium. I decided to use compressed air for makeup, as we were low in both oxygen and nitrogen. Evidently the coefficient of absorption for nitrogen in sea water at 200 ft is high, which accounts for the steady drop in nitrogen in our samples. Air makeup may be the best bet – certainly cheapest. After a short blow of compressed air, O_2 up to 4.26%, and N_2 to 17.3% at 0800. No O_2 bleed-in required. Subjects proceeded with late chow. Coffee and corned beef hash on crackers.

Sitrep* at 0830 – A long one from Barth reported that they heated two pots of water with lids off this a.m., and raised humidity too much. Dehumidifiers quickly took care of same, but next time the lids will be left on. Foam rubber suits which had not been wet had re-expanded, but not those which had been wet.

Visibility reported outstanding at 190 ft. Skindiver could see surface easily. All legs of tower visible, and a great deal of curious marine life, mostly groupers. Bottom reported 50-50 coral sand and algal growth, with much garbage and cables. All conditions good, but refrigerator does not function, as per my wager with Whirlpool. Hot water heater doing well; sanitary overboard in good shape. Plans for today's sortie to clean up debris.

Considerable diving activity today. Two photographers, McLenny and Campoli got good bottom pictures, happily. SDC made three trips, loaded both ways. One trip returned the calibrated microphone and preamplifiers. Examination revealed that one preamplifier had a dead battery, the other, no battery at all! Ah! the consummate care of the longhairs from Columbia U! They were repaired and returned for use.

At 1540, the Norden camera was lowered away for installation on the back porch. Trouble with the Arawaks was diagnosed, will be overcome. One Arawak in commission and continuous use for over an hour, using a series hookup.

Environmentally, all seems well. The heaters were all secured about 1200, and internal heat is being maintained nicely by the normal heat-producing electrical equipment inside Sealab I. Temperature 88.5°F. Oxygen and nitrogen control are relatively simply, and may be at least partially controlled with compressed air as well as with helium and oxygen. One Mk VI, today, lasted only 45 minutes, but suspect gas leak while lying in Sealab, due to rough handling. Subjects report fairly severe cold after 30 minutes bottom exposure, but no heat loss recorded, oral temperature.

Problems of lowering objects direct to Sealab continue to plague surface tenders, who miss their mark regularly. Tomorrow, a dumb-waiter system with shackle and basket on descending line will be rigged, for guaranteed delivery to back door, no-hands.

The CO_2 scrubber operation appears to be at an absolute minimum. Could it be that the open sea-water wells are acting as salt water scrubbers? We'll know in another 24 hours.

*Situation report.

Am convinced that the major problems of any exercise such as this are those of material handling from and on the surface, and of adequate communications. In this case, it has taken us 24 hours to square away these problems, which is near record time. We now have the best communication network yet developed, and it is tremendously helpful. Finally, the helium voice unscrambler is nothing less than terrific. No helium diver should be without one.

Medical: At 1700 comes a message from Dr. Thompson: Thompson and Manning have headaches; all subjects have creaking joints; Barth has pain in left shoulder. Aspirin recommended for all hands - much mule-hauling hard work and exasperation today.

Early evening spent in physiological measurements, horseplay, photography, and marine bird-watching. The Birns-Sawyer underwater light burned out after 3 hours of use, killing the Norden camera shots. Discussed the problems of raising Sealab I with crew, who are prepared for a long run in SDC if need be. Discussed further the poor coordination of SDC utilization and communication, promised better tomorrow. Properly relieved of watch at 2150-by CAPT Mazzone.

JULY 21, 1964
ON DUTY: CAPT MAZZONE

The one significant fact considered worthy of note is the expression by Manning, to the effect that man is small and humble and indeed awed in the diurnal happenings beneath the surface of the sea - "Big fleas have little fleas upon their backs that bite 'em, and little fleas have lesser fleas, and so ad infinitum." I honestly feel that Manning suffers the early spark of intellectual curiosity in the field of Oceanology.

JULY 22, 1964
ON DUTY: CAPT BOND

Assumed the watch at 0530. All conditions normal, save that our number 1 monitor failed during the night. Number 2 TV monitor still functional, however. Barth has the watch at the present time, remainder asleep.

Subjects should report fair amount of fatigue and sore muscles today, as their physical exertion over the past two days has been considerable.

Outside weather: cumulus and rain clouds; surface winds about 5 knots, SSW, occasional gusts to 15 knots, swells 1-3 ft, generally good.

Morning situation report with Barth over the wonderful helium voice unscrambler. Mostly chitchat. Reports he feels good; visibility good - 100 ft. Complaints that the Mk VI with double 90's is too big and unwieldy to handle in Sealab; difficult to don, extremely heavy, requiring too much lead for negative buoyancy. Accordingly, we will switch today to smaller Mk VI for balance of run - probably safer.

In reviewing scrubber operation vs CO_2 levels, it is evident that we are getting a significant amount of scrubbing from sea water, although intermittent use of the scuba gear is also a minus factor.

After discussion with Bob Thompson regarding atmosphere and water level, decided to blow water level down with air at 0715, and repeat gas analysis at 0800. This trick of using air for makeup is money in the bank, and all hands happy. Next generation of Sealab will make even better use of the sea environment - will check on, and log, solubility coefficients of all important gases in salt water today.

Went over diving and SDC schedules with Bob Sheats this a.m., and all lines of communication are clear. First ascent run of SDC very well coordinated, efficient. At 0915, O_2 - 4.55% or 31.15% effective. N_2 - 19.5%. Will watch and measure the N_2 decline.

Later in the day, will record Manning's description of his marine watch. Last night he reported seeing a 400-lb tuna, feeding on the schools of jacks around the Lab. This should be described in detail.

At 1000, preparations for photography were commenced, and shots taken of two divers in Mk VI gear, one on Arawak. Immediately after entering water, the No. 29 Mk VI was found to be out of gas, so Manning came back quickly. By 1200, all divers were returned to the habitat – Mk VI No. 30 read 750 lb manifold pressure. Temperature at 1200, 89°F, mostly heated by Arawaks, which had operated for almost two hours.

As the day wore on, subjects took short rests, then got busy with chores inside and out. The dumbwaiter was eventually rigged and functional; the SDC is on the crane. By 1700, the recharged Mk VI rigs were returned to Sealab I, and external TV was mounted outside the back porch.

A conference was held today with Roy Lanphear, Al O'Neal, and Dr. Bond, relative to an agreed mode of raising SeaLab I at end of the run. It was agreed that, with a dynamometer installed on the crane, the habitat would be raised on the Argus crane until such time as the surge caused significant stress on crane or island structure. At this point, the aquanauts will transfer to the SDC for raising to the deck of Argus and completion of decompression. Meanwhile, Sealab I will be returned to the bottom on compressed air, to be lifted a little later, buoyed off, and towed clear of the site for deballast and return to Bermuda. At present the umbilical cord is loosely attached to Argus with a nylon line, in event YFNB-12 must break umbilical and bug out.

Blood and urine samples obtained at 1800 today, for processing tonight.

JULY 23, 1964
ON DUTY: CAPT MAZZONE

The situation for night routine does not vary. One important point this evening was the placing in commission of the current meter. The current is listed as well below 0.25 knots.

Wet Bulb	- 83°F
Dry Bulb	- 85°F
CO_2	- 0.2%
O_2	- 29.5% effective (4.6%?)
H_2O	- 25°C
H_2O W Trunk	- 5 ft 10 in.

JULY 24, 1964, 0500
ON DUTY: CAPT BOND

Relieved the watch at 0500. All personnel and systems normal through the night. Had one-hour closed-circuit conversation with Dr. Thompson for a cumulative sitrep to date. The following pertinent information obtained:

Medical

Generally, it is noted that, after commencing stay in Sealab I, all subjects slowed their pace of activity. This has been noted in the early days of each previous chamber run, and in all of Cousteau's experiments. Possibly, the organism shifts to lower gears, awaiting acclimatization and meantime conserving energy. All necessary work is ultimately accomplished, but at a slower pace.

A sense of easy fatigue, coupled with joint (shoulder) discomfort, creaking and cracking, common to all, but diminishing day by day. Headaches (mild) noted after prolonged outside activity. Appetites good, digestion and elimination normal, sensory preception unchanged. No skin problems, or ear trouble. Wound healing was unimpaired. Sleep cycles unchanged, but siestas required. Pulse rates, respiratory rates, and blood pressures all lower than

base line. Pulmonary breath sounds different: all predominantly bronchial sounds. Slight upper respiratory infections the first day; now cleared up. Dream activity about normal.

Psychological

General group sense of independence from surface support, unlike chamber runs. Interpersonal relationships remain good, though mass group activity minimal; rather, each does his own part of the job independently. Personal idiosyncrasies are accentuated, but not annoying. More introspection, meditation, and inner-space watching than was anticipated. Psychological tests performed willingly. Slight hostility to some orders from surface, resistance to unreasonable topside demands, irritation with topside lack of coordination. No particular desire for two-way TV monitors, but long phone conversations pleasant. Occasional desire to share perceptual experiences with topside attendants. Little or no tension with regard to safe control of environmental situation.

Marine Biological

As previously noted, a considerable amount of inner-space watching, and identification with marine environment. Some successful fish feeding. Marine specimen collection difficult, due to odor. No microscopic studies yet, but gross in vivo studies continuous. Night observations most productive. Large tuna feeding noted at night. Two large sharks sighted last night. Do not believe Sealab I particularly disturbs local ecology. Keeping log of marine population.

Generally speaking, these long phone conversations are very productive, the more so because of the efficiency of the He-O_2 voice modulator - a remarkable device. All told, our present communication system is par excellence. The closed-circuit TV is especially valuable. The electrowriter gives a very useful permanent record. Thus far, the chromatograph has been a failure, though all other gas monitor systems have been excellent.

At about 0900, general activity commenced while taking blood samples, transporting minor items via the dumb waiter, and soliciting general comment from Sealab I aquanauts. A few things deserve special attention and record. First of these is the fact that space arrangements for donning the swim gear are poorly located and show lack of planning. The aquanauts must don some exceptionally heavy scuba gear, then climb down a steep vertical ladder to enter the water. On emerging, the climb up requires considerable physical effort. The whole setup tends to discourage spontaneous sorties, and makes each short working dive an unhappy event. The dressing station should be on the ground floor, avoiding all necessity of climbing with gear.

A second, and more serious consideration, concerns the maintenance of a compressed-air compartment separate from the He-O_2 living space. I feel that, while a separate and isolated space is desirable for any undersea house, it should contain 50-50 He and air, rather than air alone. After helium saturation, and maximal nitrogen elimination, we find that the depth of nitrogen narcosis is a great deal more severe when exposure to compressed air occurs. So much so, that I was genuinely alarmed at the reactions of my aquanauts when they were in the air space for any length of time. Consequently, today we diluted the air mix 50-50 with helium, and will do likewise with the mix in our double 90 open-circuit scuba, which formerly was charged with compressed air.

This is a brand new finding in diving physiology, and can easily be tested in the laboratory. It will be pursued at New London soon.

Finally, one has the sneaking suspicion that in this artificial atmosphere at this pressure, more than 160 mm O_2 may be required - for this, animal experiments with arterial partial oxygen determinations should be done.

Following lunch and a siesta, the afternoon sorties are planned.

Afternoon sorties involved use of Arawak gear to 50 ft away from Sealab, depletion swims

of both Mk VI apparatuses, and one set of double 90 compressed-air scuba. Short inspection tours of the NE and SE legs were accomplished, and some cleanup of debris. New TV camera was placed; current meter relocated (max. reading 0.3 kt), and a fair amount of underwater photography.

Attempts to sample bag levels in Mk VI will probably be discontinued, since He loss is so great through sample bag that all O_2 readings are abnormally high. This procedure is best done at EDU, not good in the field.

Weather and sea state remain satisfactory, with wind and low swells from due east. Bottom water temperature 70°F today, with somewhat less visibility, due to zooplankton. Subjects in excellent spirits, report more energy, as anticipated – diving sorties secured at 1600, though back-porch sorties will continue. Atmosphere in "air" compartment now diluted with helium, and is a safe mixture. Communications are excellent.

JULY 24, 1964
ON DUTY: CAPT MAZZONE

The night watch generally is not too productive, except for picking up isolated facts.

In shifting from the "air" space to the helium space, one becomes more aware of odors associated with the "lived-in" compartments. Charcoal canisters will be used in the standby manifold.

The LiOH canisters were changed this, the fourth day. Apparently the humidity is higher than one might expect, since the canisters were swelling almost to a burst point on the ends.

JULY 25, 1964, 0530
ON DUTY: CAPT BOND

Assumed the watch at 0520; all conditions normal and satisfactory. Weather: cumulus clouds ring the horizon; intermittent rain squalls probable; light winds from the east; low swells 1 to 3 ft. I forecast a day similar to yesterday. Full moon tonight. Will request outside night observations after moonrise.

Today we may have planned combined operations with the miniature submarine STAR I. In this exercise, it is anticipated that the sub will attempt to make a suction seat on a boiler plate located on the ocean floor 50 ft south of Sealab I, in view and photo range of the aquanauts, who will assist in evaluating the performance of the craft. It is anticipated that STAR I will be handled from the PETREL, and towed to this site by her whaleboat. STAR I is determined to have a speed capability of 0.8 knot, which is marginal, but should work, since the maximum bottom current recorded thus far is 0.3 knots.

Yesterday, on a sortie to Argus Island tower, Anderson inspected welds at SW and NE legs, pronounced them clean and satisfactory. Tags were placed on these two legs for photo identification. Experiments at fish feeding were partially successful, will be resumed today.

The aquanauts are now past 84 hours of bottom stay, with no significant change in physical condition or psychological response pattern. One observation worthy of note concerns their relations with topside support personnel. Although they are occasionally abrupt, curt, and openly critical in some of the short verbal exchanges with Sealab control during work periods, when multiple orders and demands are made both ways, they thoroughly enjoy long conversations on the helium unscrambler phones with any of the topside support personnel and with those crew members of YFNB-12 who have shown a continuing interest in the program. These conversations are possible in the early morning hours, immediately after evening chow, and at intervals during the late night watches. There is no evidence, in these talks, of nostalgic moods or rumination: they share their experiences and enjoy humorous exchanges, with rare

reference to current events elsewhere. It is possible that the unscrambler makes for better relations, since it must be extremely aggravating, after enunciating with much care, to be told abruptly, "Say again - I don't read you!."

Last night, we sent a half watermelon down to the aquanauts for a surprise dessert; and later our ship's cook prepared a magnificent package of home-made fudge for their enjoyment. If time and logistics permitted, these little things would be more frequent items on the agenda; but with our enforced compression of schedule, it cannot be.

I suppose that a note is in order relative to the state of mind of the two watch-standers of the experiment, Walt Mazzone and myself. It would be accurate to say that we enjoy a feeling of considerable confidence about the entire project. Our subjects are well trained and capable of appropriate handling of emergency situations. Our monitor and control systems are functioning better than could have been hoped for, and plenty of backup available. Finally, neither of us have had any misgivings about the operational success of the project, once the aquanauts were on the bottom. In all, I would say that we have less apprehension than almost anyone aboard. The matter of returning the subjects to the surface is somewhat different, since some engineering phases of this span of time are not under our direct control, and will require most rigid and demanding attention to detail. The decompression concept which we will follow is not understood, nor can it be shared, with respect to the riggers responsible for raising the habitat and the SDC; hence I look forward to a difficult period at the end of the bottom stay.

Afternoon spent in continuing outside activity and photography - very good material. Later, civilian photographers got night shots of Sealab I, and early scenes of documentary were shot by mobile Photo Unit (Norfolk).

Properly relieved by CAPT Mazzone.

JULY 26, 1964, 0545
ON DUTY: CAPT BOND

Assumed the watch at 0545. All conditions normal through the night; subjects slept well, made a few marine observations through the night. Late taps - after 2300, due to movie requirements and long technical discussions on helium unscrambler.

Weather clear with scattered cumulus clouds, brisk wind from SSE, 8 to 10 knots, no visible current on surface; bottom current less than 0.24 knot, seas choppy, very little swell, pressure in Sealab I 93.8 lb absolute.

Spent 30 minutes on scramble phone with Barth, going over test procedures for SDC on Argus Island today. He reports all subjects ready for any type of decompression procedure required. Plans for today are much underwater photography, some coral and bottom sediment collection. Mk VI usage has improved markedly, and greater mileage being obtained on the double 90's with 50-50 He-air.

By 0930, winds were up to 20 knots, with occasional gusts to 30 knots. YFNB holding well in moor, with heavy strain on port bow line. During night, the TV coaxial cable parted to Argus Island, was not yet spliced at 1000 today, despite three requests. Subjects report presence of a number of very large tuna around Sealab I, got a few pictures. When the outside TV camera is on line, we can get Kinescope pictures of them.

In checking our supplies for terminal SDC decompression this a.m., we found that the air bunks had been stolen or lost. It might have been expected, since these items are attractive; but they are also vital to the safety of the program, and it is discouraging to see such things happen - everything was under lock and key most of the time, but pins can be removed from hinges, and such was the case.

The STAR I craft is now aboard the barge, but will probably not be put in the water until the wind abates. Further, we have no divers to spare as assistants, so should rely on PETREL personnel for these early test phases. Later, when the actual simulated runs begin, our aquanauts will be able to provide observer-photographer services.

During the late morning and early afternoon, diving activity was quite heavy, on the part of both surface and subsurface scuba crews. Aquanaut activity included a wide sight-seeing sweep of a 90-degree quadrant to north by Barth, who covered about 500 yd, with Dr. Thompson riding shotgun inside the perimeter. This was followed by fish feeding, coral-ball gathering, and posing for photographs.

By 1500, the wind had picked up to around 25 to 30 knots, broad on our beam, and we had slipped a good way north in our moor; there was a heavy strain on our port bow moor leg (polypropylene), and the moor was in hazard. An hour and a half later, some line was paid out on the port stern leg and the port bow leg taken in about 70 ft, bringing the weather on our port quarter, and causing the ship to ride much easier. Anticipating worsening weather during the night, a spare 440-volt power cable was passed from Argus Island to Sealab I, as a source of continuing power in the event that weather required us to cut the umbilical and slip out of the moor.

In earlier anticipation of such a situation, the helium, oxygen, and LiOH stores on Sealab I had been inventoried today, revealing adequate supplies for a self-sustained bottom period of about six weeks – a very comforting inventory, all told, should YFNB-12 be forced to abandon her charge. At 1750, the bottom current had risen from an early 0.12 to 0.2 knot to a maximum of 0.36 knot.

Also in anticipation of longer work periods in the "air space," decision was made to equalize that atmosphere, after the power cable had been brought into the space. Barth exited at 1945, using nearly empty double 90's to get the power cable from Argus Island. After two attempts, he succeeded.

Later weather report predicts 35 knots peak winds tonight. Port bow line the questionable factor of this moor. Communication link from Argus to Sealab cannot be established tonight.

At 2100 the emergency power line was brought into the air compartment and available for hookup. The air compartment was flushed with air, then 300 lb pure helium added slowly. This mix will be sampled in 90 minutes.

Properly relieved at 2110 by CAPT Walter Mazzone.

JULY 25, 1964
ON DUTY: CAPT MAZZONE

At 0100, sampled the air-space atmosphere, and had both air valves secured as per previous orders. Asked subject, Manning, HMCA, to verify the presence of LiOH hand-operated manifold assembly.

JULY 26, 1964, 0500
ON DUTY: CAPT BOND

Assumed the watch at 0500. CAPT Mazzone reports a quiet night watch, no significant events other than failure of electrowriter at 0100. Gas analysis in air space showed an O_2 of 4% – too low for our purposes. Will correct this deficiency this a.m., with compressed air bleed-in.

Weather improving, with light SSE winds, 3 to 5 ft swells, squall-line clouds on the horizon. The predicted 35-knot winds evidently did not develop during the night. In any event, we are prepared for almost any kind of bad weather, insofar as Sealab I is concerned, so long as she rests on the bottom.

Plans are to draw bloods early today. There will be two photo runs from the surface, one at 1120, next at 1500. Today is not exactly holiday routine, but it should be a relaxed routine. If telephone connections can be established, the subjects can make phone calls to their wives (lucky bums), and tomorrow a telephone interview with mainland reporters. No shore boat run today, so no electric hoist until tomorrow. STAR I will probably be launched from YFNB-12 today, for preliminary tethered trials, PETREL divers assisting - correction - no assists.

Brief sorties were accomplished in late morning and at about 1600, for photographic purposes. Bloods were drawn shortly after the last sortie. SDC run was made to deliver broiled steak and mashed potatoes for rewarming, and to return blood samples.

Subjects active and generally in good spirits today. All report some weight gain. Diuresis is the rule with all scuba divers when in the water, although blood urea nitrogen values have not risen above normal. At 1500 today, subjects complained of rapid breathing; subsequent CO_2 check revealed 0.5% CO_2. Canisters were ordered changed, which rectified the situation. This makes a total of only eight canisters in a total time of 144 hours - not bad! Oxygen requirements are also easily met - a very smooth control of atmosphere.

Continued trouble with the mercury batteries for the preamplifiers used in conjunction with the calibrated microphone. All batteries give out after an hour or so, else fail from the start. Trying different combinations and ordering new batteries, but trouble probably in preamplifier. Electrowriter has failed twice: once, when dropped during heavy seas; and again for undetermined cause today. Both times readily repaired by Ralyea, YFNB-12 ET1.

Properly relieved at 2200 by CAPT Mazzone.

JULY 27, 1964, 0530
ON DUTY: CAPT BOND

Relieved the watch at 0530. CAPT Mazzone reports all quiet and well during the night. Interviews were held with Barth during the midwatch by Roger Vaughan and others, and Anderson quizzed a bit. Am not sure about reliability of some of this information, but will let it pass, subject to review.

Weather this a.m. is ideal. Wind from south at about eight knots, nearly flat sea, low swells (1 to 2 ft) from SW, scattered cumulus clouds.

Tethered tests of STAR I completed by 0900, all successful. Decision to do deep seat tests about 50 ft south of Sealab I, with underwater TV coverage and aquanaut assistance. Scuba equipment in Sealab at 1000: 1-1/2 Mk VI gear, two double 90's joined with He-air mix. For this operation, the SDC is hanging on Argus Island by a wire pennant, the area cleared. Currents run from 0.2 knot to 0 knots on bottom.

Yesterday, Anderson spiked a temp. to 100.1°F.; today both Anderson and Thompson have 100.1°F, no symptoms. Have advised against excessive exposure today, will watch white blood count and urines, for aid in diagnosis, if any.

Subjects are independent as hogs on ice. On several occasions, after one-way communications with Argus Island, they have proceeded on a course of action without notification or concurrence of Sealab control. In addition, O_2 bleed-ins have been made without notification, and gratuitous suggestions made on methods of atmosphere control. They have been chewed out, and threatened with a break of communication with Argus Island, unless they mend their ways.

At about 1600, Tiger Manning returned to Sealab I after a brief photo tour, using the Mk VI gear. He lost consciousness on the back porch, and was hauled into the habitat and revived with no worse effects than a flame hemorrhage in the left eye. Cause of casualty: excessive CO_2 (wrong!, see later note in LOG addendum) due to improper adjustment of exhalation valve. All subjects duly warned on buddy diving practices and more careful use of gear.

STAR I tests were completed satisfactorily, and well covered photographically, with a total of six runs being made. STAR I returned to Bermuda Naval Station, and the new two-ton electric winch was installed for SDC control. Dispatch was sent to CNO at 1500, outlining plans to commence decompression Monday, July 31.

Properly relieved by CAPT Mazzone at 2100 hours.

JULY 27, 1964
ON DUTY: CAPT MAZZONE

In general, night activity is quite subdued.

Subjects reported excellent results with steak dinner.

1. Took the opportunity to discuss the role of subjects, topside assistance, investigators.

2. Since Manning's near tragedy, it became increasingly more important to renew the interests in buddy diving; secondly, it is extremely important to report each time someone enters or leaves Sealab.

3. All conditions should be reported, such as scrubber operation, gas addition.

4. Lastly, though not least, was the question of language and lack of respect manifested by the subjects - this defect has been recognized and will be rectified.

JULY 28, 1964
ON DUTY: CAPT BOND

Relieved the watch at 0545. Weather continues good: scattered clouds, cumulus; wind from south, 5 to 8 knots; seas relatively calm, with 1 to 3 ft swells out of SW. Forecast day much like yesterday. Subjects rested well during the night. Argus Island communication link completed yesterday p.m., very loud and clear, but interferes with Sealab I diver phone communication.

Am constantly struck by the difference between the Sealab I exposure, and that of Cousteau's two volunteers, who stayed in the 85-ft habitation for about a week. In our case, the inhabitants have been quite comfortable throughout, in contrast to Cousteau's men, to whom the stay in deep house was a constant torment, with continuous discomfort, insomnia, and severe mental depression - in short, a severe ordeal. Here, I believe that the critical difference may well be that of humidity control, although there were undoubtedly many additional factors, which I will examine separately in the Sealab I Report.*

In attempting a comparison between Sealab I and the Cousteau 35-ft habitation, there is considerable difficulty in seeking parallels. In the first place, the Starfish house of Conshelf II was situated at such a shallow depth that the inhabitants knew they could return to the surface virtually at will, with minimal or no decompression.

In Sealab I, however, the subjects are well aware of the fact that they cannot reach the surface under any circumstances, save through a period of lengthy decompression. Again, in Cousteau's experiment, his subjects were reported to have suffered from moderate to severe dermatological disorders throughout their underwater stay; this has not been the case with our aquanauts. Finally, residents of Starfish house were subjected to many daily visits of surface inhabitants, who invaded the habitat at will, and apparently without invitation. In our case, surface divers are forbidden to so much as put their head up into an access trunk, much less enter the home of the aquanauts.

*A separate report being prepared by Dr. Bond.

Of some medical interest is the fact that both Anderson and Thompson have been mildly febrile, though asymptomatic, for three and two days respectively. Blood and urine values give no clues to the conditions described. Both subjects report feeling well.

Ambient temperatures in Sealab I now are running 83°F to 86°F and reported comfortable. Humidity is marginal – more dehumidifiers indicated for next run. There seems to be acclimatization to both lower air and water temperatures, which is an agreeable finding. The trolley line is at last repaired satisfactorily, and in frequent use. SDC used only about once daily. due to handling problems.

Shark-attracting equipment and technicians arrived today, and plans currently underway to place all gear tonight for the experiment. Of some marine biological interest is the diurnal migration of fish species and the fact that our groupers change coloration according to the ambient light and environmental background, rendering identification difficult, no langouste yet seen, a few morays, some quite large, and the rare large barracuda comes low about twice daily. Daily, at about 1600, a school of Permit comes swooping down, displacing other fish almost altogether. This display lasts about 30 to 40 minutes; then, as the Permits leave, the groupers, formerly huddled beneath the Sealab I hull, come out in schools, but soon break up into their characteristic solitary meandering patterns. Finally, just before dark, the amberjacks and small tuna feed near Sealab I with considerable flourish. And then comes night, and we above miss the night show.

At 1800, Sealab I made clear voice contact with Tudor Hill Lab; plans are now afoot to call families at home, possibly tomorrow, or even tonight. This will surely be a first in anybody's book. What a surprise for the wives!

A requested TV camera did not arrive today; nor did the long-lost Collins respirometer. The latter is sickening, and no credit to the people involved in sending or tracing it.

New 2-hp electric winch secured today to handle the SDC. We propose tomorrow to test a dry run of placing SDC on top deck of Argus Island, and testing method of canting it over on deck, using a chain fall. Am hoping we can prevail to bring Sealab I and occupants as near the surface as possible during decompression, preferably all the way.

JULY 28, 1964
ON DUTY: CAPT MAZZONE

Once again, the uneventful night vigil. The Sealab watch is quiet, responding only when called. Subjects quite elated about the possibility of making phone calls to family and friends.

The many cables now going into and around Sealab constitute quite a diving hazard – relative to getting caught with the diving rig.

JULY 29, 1964
ON DUTY: CAPT BOND

Relieved the watch at 0445. Weather humid, warm, overcast, light wind from south, 1 to 3 ft swells, no wave action; showers likely. Sea state continues ideal for raising operation.

The TV camera reported delivered to Tudor Hill yesterday should arrive on the boat from shore today for installation inside Sealab to replace a faulty camera. In lowering shark-experiment lights last night, had multiple implosions before reaching bottom, destroying all lights. Will pressure test a new set today, prior to lowering. Marine Lab technicians certain the damage caused by rough handling; they will have opportunity to handle their own gear today, to forestall criticism.

A partial equipment evaluation is in order at this time:

Thermoelectric Refrigerator

A complete failure in He-O_2 atmosphere, as in three previous trials. Clearly, function of this equipment is marginal in sea-level air, and it will always fail under Sealab conditions. Next generation of Sealab must have a freon-charged compressor system, isolated in a separate compartment to avoid atmosphere contamination, with induction cooling of brine pipes to chill box in living space.

Arawak (Hookah) Systems

Possibly because of the overhauls, and fitting of parts with tolerances too close, the Arawaks pulled far too much amperage (11 to 13 amps) in operation, finally had to be operated in series, with one man on watch at all times during operation, to anticipate gear failure due to overload cutout. It is possible, but not likely, that gas density was a major factor. This equipment had been previously tested at gas densities equal to three times sea-level air density, and did not then approach an overload. Will get another sea-level test in Bermuda, on return.

Charcoal Filters

Marginally effective, probably inferior to $KMNO_4$ for routine odor removal. Electrostatic precipitators must be considered for refit of Sealab I for next run. Some pan broiling, pancake making, etc., most desirable, and filter-purification system should be designed to allow for this.

Ambient Temperature and Humidity

Should be recorded and monitored automatically. Sling psychrometer too time consuming. Heat control should be by thermostat, not by hand.

Dehumidifiers

Function well, but control marginal, due to insufficient capacity. Cooling brine coils, plus added number of standard dehumidifiers (four more) should do the trick for five people.

Electric Blankets

Function well, should be retained; but they are a source of 60-cycle interference with electrocardiogram, other sensitive instruments, must be secured during use of these instruments.

Communication Systems

Excellent, but need additions and sophistication. We should have radio (voice band) telemetric buoys for two-way marine-band broadcast reception. All communication systems should have a "call" light on instrument. Helium unscrambler is outstanding, needs a little more sophistication of unscramble switches for two-way conversation, and recording plug-ins which run on minimal gain for drive. Should be located in TV monitor range, as it is helpful to observe speaker during conversation. This system eliminates need for "air compartment." Electrowriter generally excellent, but requires more training of operators, should be two-way system, and requires good orthography. Technician for adjustment and repair of topside unit desirable; multiple spare parts a necessity; should have automatic take-up spool for preservation of written record.

Television

Two-way closed-circuit TV monitor system an absolute must for this type operation, with one- or two-way system for outside environmental observations.

Hot Water Heater

A must, for hot showers after cold-water exposure; capacity marginal, could be larger - very satisfactory performance.

General Plumbing

Overall satisfactory.

Lighting

All lights and reflecting surfaces must be coated to eliminate hot spots which will burn cameras. External lights should be attached to hull, and given protective fairing.

Ballasting

Requires complete reengineering, more emphasis on water ballast, semiautomatic ballasting and deballasting methods.

Access Trunks

Should be of equal length, more easily entered, should be fitted with water-level alarm devices. Possible use of salt-water jet curtains should be considered, for CO_2 and N_2 scrubbing, to reduce load on LiOH scrubbers.

Umbilical Cord

Unsatisfactory; requires complete reengineering, with waterproof coupling through the hull, no gas leaks. Cord should be single integral unit for all housekeeping requirements.

Swim Gear

Marginally effective; Mk VI batting average 0.425; cannot stand rough use or handling; strict training program, continuous refresher use required of all aquanauts. The swim-gear space should be completely redesigned to permit don and ditch in absolute comfort, with plenty of room, and no effort. Checkoff list posted in swim locker, and rigidly followed.

Internal Instrumentation

Barely satisfactory; needs sophistication. Safe means of calibration required for O_2 sensor. Automatic O_2 bleed-in devices desirable but must be fail safe. Recording current meters and recording absolute pressure devices a must. Recording external light meters desirable: ditto recording BT's.

Topside Instrumentation

Perkin-Elmer fractometer very reliable, not prone to seasickness. Beckman chromatograph no good for shipboard use. Dwyer reliable for shallow depths. Need O_2 and CO_2 sensors of much greater sensitivity and reliability. Absolute pressure gages excellent, should add a Heise, have topside means of calibration.

Laboratory Instruments

Special attention to eliminate all seasick-prone devices topside – requires special report. Automatic analyzer probably a must for next operation.

At 0630, weather, wind and sea have backed around to SSE, kicking up with increasing wind velocity. Anticipate a moderate two day blow (personal forecast). All well below, subjects in satisfactory condition. More shark work today, plus checkout of electric winch and SDC positioning. Last night's clear communication with stateside ham operators promises interesting talks with aquanaut families and press conferences.

A long conversation with Barth at 0700; discussed Sealab raising procedures, general items; all well, and subjects amenable to any course of action dictated from topside. Weather report at 1300 indicates severe tropical disturbance 700 miles SE; procedures for prelift preparation of Sealab I rehearsed, and set into action.

JULY 29, 1964, 1630
ON DUTY: CAPT BOND

Preparation for Liftoff

Commencing at 1400, preparations for Sealab I liftoff went ahead through the afternoon and night without letup. Weather conditions at the time were ideal, but forecast was for severe tropical disturbance to pass near at hand or hit directly, with high winds and seas within 18 to 24 hours, and possibility that YFNB-12 could not hold in the moor. Hence, the decision was made to commence premature lifting of Sealab I with occupants, to get the habitat as near as possible to the surface before it became necessary to return it to the bottom, and the aquanauts to the SDC for terminal decompression.

All cable attachments from Sealab I which were fixed to the bottom or to the tower were cleared and placed in the habitat. An emergency power cable was passed to Sealab and secured in the air space. Emergency communications were maintained with Argus Island. An electric winch was placed on Argus, for better SDC handling.

Four ballast anchors were lifted individually from the ballast bins, lifted to Argus Island, where they were married, and one set installed at north end of habitat, to anchor a running 4-in. nylon hold-down line, for terminal control of Sealab. Lowering of forward group was discontinued because of hazard of handling in dark.

Two hold-down bridles were attached to towing padeyes at either end of Sealab; all divers' lights were placed in the bins. The crane hook was connected to the lifting bridle and moved in.

The air space was ventilated and filled with fresh air. All communication systems were rechecked, and procedures for entering the SDC were established. All scuba gear, save one lost set of bottles, was replenished and stowed on Sealab.

The SDC was raised to 175 ft by pneumofathometer reading, and a line connected to Sealab. The trolley line was attached to the shark cage, and slacked. Oxygen level in Sealab was raised to 9.0%, and decompression rates discussed, with adequate communications between trailer, Argus Tower, and Sealab.

The subjects entered SDC at 2345, and Sealab liftoff was accomplished smoothly to a height of 8 ft above ocean bottom. At 2400, subjects returned to Sealab.

Decompression was started from 169.9 ft and was commenced at 0100. Properly relieved by CAPT Mazzone at 0130. CAPT Mazzone on duty 1100 to 0100 with me.

JULY 30, 1964, 0100
ON DUTY, CAPT BOND

Decompression Log

Actual decompression in Sealab I commenced at 0100, after subjects had taken 45 to 50 minutes rest period in Sealab. Procedures went smoothly, with excellent crane operation, no evidence of significant strain as per dynamometer readings. Reached 150 ft at 0740 this a.m., all subjects resting well, no problems. Communications clear and ungarbled in all directions. Lift is alternated between 0.45 and 0.46 psi every 20 minutes, which gives desired average 0.455 psi per 20 min.

The threat of high winds and seas did not begin to materialize until the vening of the 30th, when the tropical disturbance was reported passing 200 mi to the east of Argus Island. At this time, long swells began to build up, sweeping from NE to SW, and gradually reaching 10 to 12 ft peaks, without significant winds. By 2100, the Sealab I was feeling regular deep surges, giving dynamometer readings of up to 14 tons on the crane. These surges reached 15 tons by 2200, and the first of many "holds" was agreed upon between Argus Island on-scene commander and Sealab control. Lift was cautiously resumed at 0000 31 July, but many holds were required throughout the early morning, with little upward progress of Sealab I and its occupants.

JULY 31, 1964
ON DUTY: CAPT BOND

Relieved CAPT Mazzone at 0445. The decompression watches have been shortened to six hours, heel and toe, with some overlap. Seas were running high, with swells approaching 15 ft, NE to SW, and still no winds, which had been predicted to 45 knots by 0600 today. Strains on the lifting crane had become severe at 80 ft depth, with dynamometer readings to 17 tons, by 0700, when a hold had been in effect for three hours.

After consultation with LCDR Lanphear, it was agreed that Sealab I must be evacuated. The aquanauts were given a situation report, and evacuation to SDC was accomplished at 0735. The SDC was held at 81 ft on the electric winch from Argus Island, and Sealab control personnel were split. CAPT Bond went to Argus Island to continue in-water decompression of subjects in SDC, with CAPT Mazzone in trailer to coordinate gas provision to Sealab I, and complex communications.

As decompression in the waterborne SDC continued, directed from Argus Island, decisions were made relative to disposition of Sealab I. In anticipation of surfacing the habitat, work was undertaken by surface divers. The umbilical cord was removed and retrieved, and all hull openings buttoned up with exception of the umbilical hawse, which was left open. The four 2000-lb anchors had been removed prior to liftoff, and Sealab I was about three tons negative.

At 1000, original plans to buffer surge strains with a 3000-lb surface buoy, and raise Sealab I high enough to attach positive buoyancy floats, were reversed. It appeared that the plan could not be accomplished, and that it would be necessary to lower the habitat to 193 ft, for subsequent salvage operations, when weather abated.

This decision carried considerable threat to the aquanauts. Preparation, actual lowering operations, and deep diving to retrieve the crane hook and secure Sealab I more firmly to the bottom, would have required many hours, during all of which time the aquanauts would be in a

rigid standing position in the waterborne SDC, without water, source of warmth, or any other necessities. Under these conditions, decompression efficiency would be compromised, and hazard of physiological damage markedly increased.

After weighing all factors, it was agreed that a single attempt would be made to raise Sealab I to a point at which flotation buoys could be attached, and the crane hook released to raise SDC onto Argus Island for proper decompression of occupants. Accordingly, a compressed-air hose was attached to Sealab I He-O_2 trunk, and she was lifted to 55 ft, where four 3000-lb buoys were attached to the fore and aft bridles. Because of long surges, the habitat took on considerable sea water through the open hawse pipe and loose hatches, and sank her buoys when full mass was applied. A constant air blow was continued, and the habitat finally blown dry, at which point she rode well on her buoys, and the crane hook was freed. Sealab I was floated clear of the immediate area, and SDC hoist begun.

With SDC buttoned up and pressurized to 64.5 ft, the chamber was raised vertically from the water and tipped over to a horizontal position. In the process, one fitting carried away, with considerable loss of gas. The occupants of the chamber kept up a steady intake blow, however, and depth control was adequate during the repair period. At 1320, all modifications were complete, and after a hold of 90 min at 64.5 ft, decompression was resumed, under topside control. All subjects reported well, though quite cramped and uncomfortable. The medical lock was operated, and necessary items of food and comfort were locked in. Decompression was resumed at a rate of 0.5 lb every 20 min.

At 0100, ascent rate was altered to 0.8 lb every 30 min. This was maintained until 0430, when the rate was raised to 0.6 lb every 20 min, or 1.8 lb per hour (4.05 ft per hour). All conditions normal at 0445.

At 0530, subjects were at 12.95 ft psig reading, all awake and active. The shore boat is due in at 0730, with 15 guests.

At 0805, SDC at +2 ft, buttoned for photographers, awaiting exit. Subjects restless.

Decompression complete at 0835. All subjects in good condition.

AUG. 1, 1964
ON DUTY: CAPT BOND

At 0935, following a press conference, all subjects were flown at 300 ft altitude via helicopter to Kindley A.F. Base, where complete medical checkouts were performed. That afternoon, all returned to Bermuda Naval Base. Daily repetition of medical and laboratory exams will be maintained for five days, then repeated at one, three, and six month intervals.

ADDENDUM

ACCIDENT OF HMC MANNING

At 1300, 27 July, Operation STAR I was commenced in the vicinity of Sealab I. The purpose of this operation was to determine feasibility of making repetitive open-sea false-seat attachments using a one-man dry submersible, at a depth of 193 ft. The attaching procedure was to take place about 50 ft south of the habitation; and the aquanauts were to participate only to extent of photographic coverage and rescue or assistance if the latter should be required. The plan called for a total of six "runs" by STAR I, under control of Mr. A.D. Stover, and employee of Electric Boat Division of General Dynamics. Sea state was moderate, with bottom current recorded at less than 0.2 knot, and excellent visibility.

Three aquanauts were chosen as outside observers and photographers. HMC Manning was to operate the Fenjon motion picture camera, with 50-ft film capacity. Barth and LCDR Thompson were to use still cameras, from different angles. For this sortie, Manning was wearing a full Mk VI semi-closed circuit scuba rig, while Barth and Thompson each used double 90-cu-ft open-circuit equipment for longer stays, although Dr. Thompson made at least one breath-holding sortie without breathing gear. Much of the action was visualized topside in Sealab control via the TV monitor.

At about 1550, the first false-seat run was commenced, and within five minutes, two apparently successful seats had been made. At this point, Manning returned to Sealab I to reload his 50-ft magazine, while the others continued still photography. Shortly, Manning reloaded, and swam back out of the shark cage to rejoin Barth and Thompson, about 70 ft from the access hatch.

In retrospect, it seems almost certain that, in swimming clear of the access hatch and shark cage, Manning inadvertently struck a portion of his gas-control yoke on the structure, thus driving it to the right, into a closed position. From this point forward, no additional gas mixture would be fed to the inhalation bag, and Manning would continue to "circle breath" his own exhalations, until oxygen depletion resulted in unconsciousness. Carbon dioxide would be removed from each breath by the Baralyme canister; hence the only warning of trouble to the diver would be (a) no sound of gas injection during a period of voluntary breath-holding; or (b) failure to feel or see gas exhaust through the exhaust valve on the exhalation bag, at about every third breath cycle. Since Manning was intent upon getting valuable pictures and was working close to the safety of Sealab I, he did not perform these check procedures. It is of further importance to note that the gear had been carefully checked for perfect function prior to the first sortie a few minutes before, and it was not logical to suspect any functional disorder of such an insidious nature.

In any event, Manning swam back to the photographic location, where he continued intermittent motion picture coverage for five or more minutes, unaware of an impending casualty. On at least one occasion lasting for several minutes, he was visualized, back to the camera, on the topside TV. At this time, since he was obscuring Kinescope filming of the sequence, Dr. Thompson was asked, via underwater microphone, to move him clear, which was done. Later, two topside observers, including the Principal Investigator, recalled that no exhalation bubbles were seen from Manning's Mk VI gear, although no importance was attached to the observation at the time.

After over five minutes of this action, Manning had an overwhelming sense that he was in serious trouble. After an ineffectual attempt to attempt to purge his breathing bags by use of the bypass, he turned and commenced a dash to return to the safety of Sealab I. At the point of reaching the entrance to the shark cage, he lost consciousness, and floated toward the He-O_2 open access hatch. At this point, his bottles were heard to strike the hull, and Anderson, who had inside watch, went to the hatch, thinking Manning had returned for a film reload.

Peering down the hatch, Anderson observed Manning lying on his right side at the bottom of the cage, drifting slowly aft. Anderson immediately jumped through the hatch and raised Manning's head clear of the water in the trunk. Subsequently, and quickly, he removed Manning's mouthpiece and mask, cleared his throat of mucus, and commenced efforts of resuscitation. At this point, Anderson recalls that Manning was completely pallid, "white as a sheet, including his lips," and was not breathing. Realizing that he could not carry Manning into Sealab I without assistance, he gave emergency raps on the hull, and continued revival techniques. Almost immediately, Dr. Thompson and Chief Barth returned to assist, removed Manning's gear, and began to carry him up the access trunk. At this point, Manning commenced spontaneous breathing and was able to help with the seven-foot lift to the deck of Sealab I. A few minutes later, he was recovered sufficiently for complete examination by Dr. Thompson.

The results of this examination were completely negative, except for beginning hemorrhage in the conjunctiva (white) of the left eyeball. An electrocardiogram was obtained, which showed no evidence of immediate anoxic damage to the heart, and normal rhythm. The principal investigator was notified by phones within minutes of the casualty, and kept informed continuously of Manning's condition thereafter.

Since, at the time of the accident, the exact casual factor was uncertain, the Mk VI worn by Manning was sent to the surface for meticulous examination and gas analysis of its inhalation bag content. Because of time delay, sampling difficulties, and multiple handling of the gear, the results of this investigation were inconclusive. Nevertheless, recapitulation of the chain of events, plus observations of medical significance, lead the principal investigator to firm conclusion that the events of this casualty are as stated.

In support of this thesis, a few facts warrant attention:

1. The injection gas mix at this depth, and later verified from bottle gas samples, was 85% He, 15% O_2. This mix delivered an effective O_2 percentage of $15 \times 6.4 = 96.0\%$ of oxygen. Considering the mixing characteristics of the Mk VI under normal operation, this meant that the user would normally be dealing with about a 60% O_2 effective mix, at this depth. Such a mix would enable an inactive man to survive on a single breath for about six minutes without losing consciousness. An active swimmer, however, would have somewhat less time. Thus, it is possible that Manning accidentally shut off his gas flow at the time of his first exit, partially restored his oxygen debt when he returned for a film recharge, and breathed Sealab I gas, then went back on his depleted oxygen supply, to lose consciousness six or seven minutes later. The exact sequence will probably never be known, of a certainty.

2. CO_2 retention (canister failure) was definitely not a factor. Examination showed the canister functional, and CO_2 bag values less than 0.1%.

3. There is no evidence to suggest intrinsic malfunction of the Mk VI appliance itself. All available evidence indicates that gas flow to the breathing bag was inadvertently turned off at the time of first or second sortie from the shark cage.

4. Considering the volume of the inhalation and exhalation bags, it seems likely that the accidental interruption of gas flow occurred at the time of Manning's second exit, although this cannot be guaranteed.

5. The buddy system, perhaps due to the apparent safety of this day's sortie, was relaxed; further, the use of both semiclosed and open gear by partners in such an operation should not be condoned.

After complete and careful analysis of available factors of this potentially fatal accident, it is clear that additional firm recommendations will be made. Critical review of available Kinemascope films will assist in this review.

Follow-up studies of Manning reveal no evidence of damage to any vital organic systems. The conjunctival hemorrhages should resolve in about two weeks.

APPENDIX F

SEALAB I SUBJECT BIOGRAPHIES

LT Robert E. Thompson, MC, USN

LT Thompson, 36, is married and has six children. He served as Medical Officer aboard the USS NATHAN HALE (SSBN-623) (B) from Feb. 1963 to Feb. 1964, at which time he was assigned to NMRL for duty in the Sealab I Program.

Lester E. Anderson, Gunner's Mate (DV), first class, USN

Anderson, 31, is married and has five children. He is now at Escape Training Tank as Instructor. He was formerly at Experimental Diving Unit, Washington, D.C.

Robert A. Barth, Chief Quartermaster, USN

Barth, 33, is married and has two children. Prior to his Sealab assignment, he was attached to Escape Training Tank as Instructor. He is now attached to USS PICUDA (SS-382), Squadron TWELVE, Key West.

Sanders W. ("Tiger") Manning, Chief Hospital Corpsman, USN

Manning, 33, is married and has four children. He was formerly attached to Escape Training Tank as Instructor, and was recently graduated from the School of Submarine Medicine Technique. He was assigned to Key West in connection with Sealab. At the conclusion of the Sealab Program, Manning received an assignment to Basic Submarine School (eight weeks course) beginning Aug. 12, 1964.